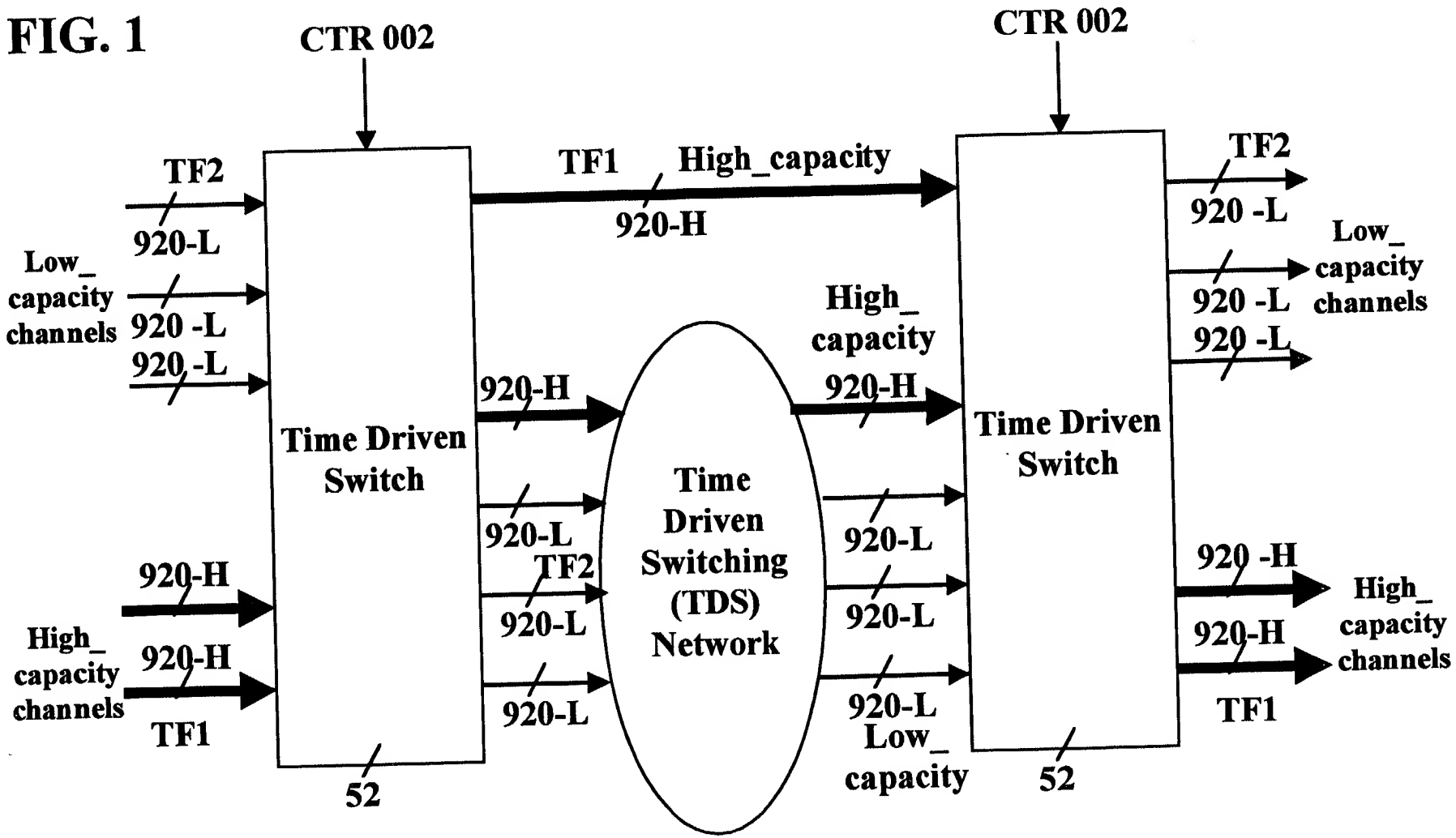
FIG. 1



c = High_capacity/Low_capacity

FIG. 2

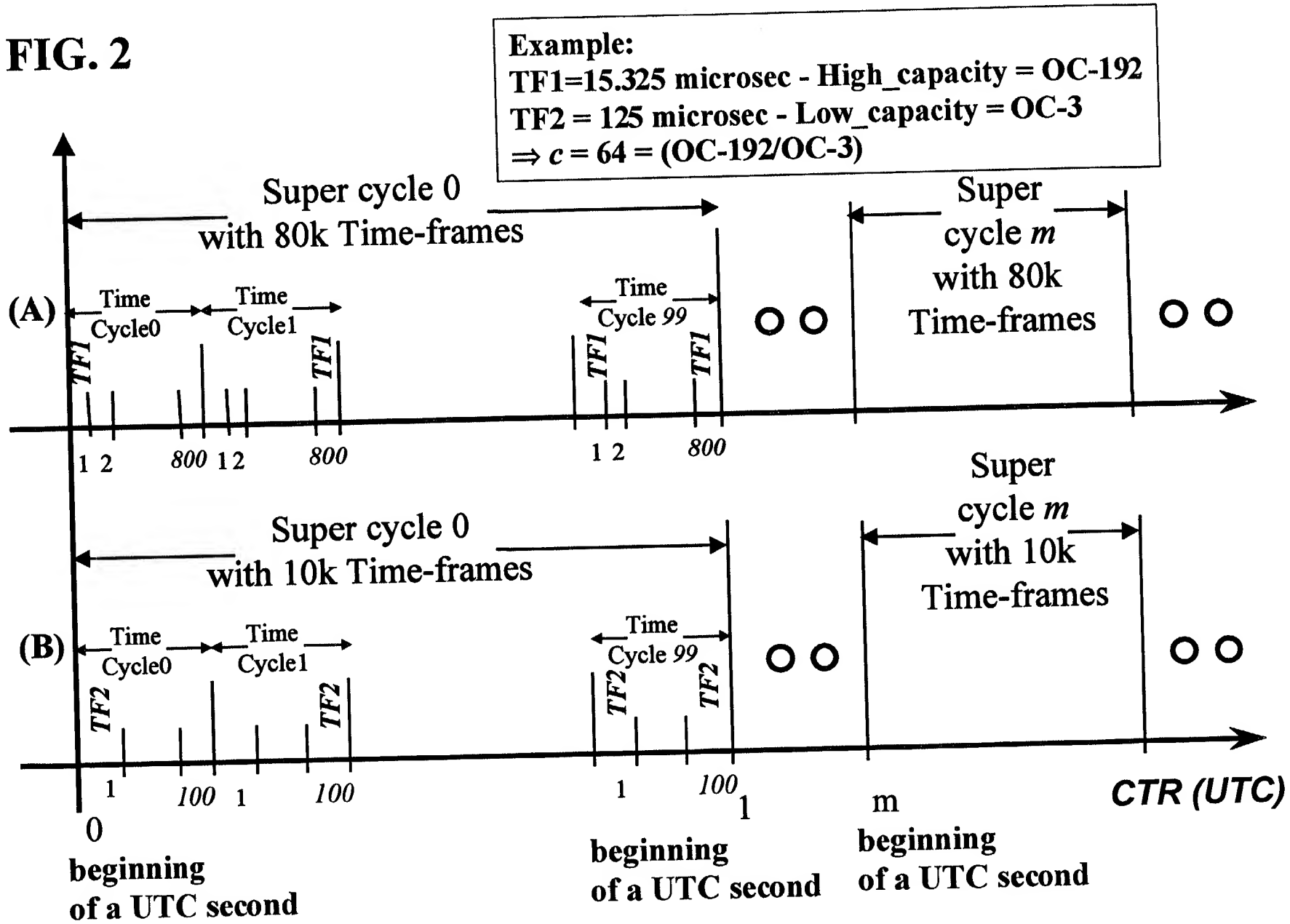

Example:
TF1=15.325 microsec - High_capacity = OC-192
TF2 = 125 microsec - Low_capacity = OC-3
⇒ c = 64 = (OC-192/OC-3)
Super cycle 0
with 80k Time-frames
Super
cycle m
with 80k
Time-frames
(A)
Time
Cycle0
Time
Cycle1
Time
Cycle 99
TF1
1 2
800
Super cycle 0
with 10k Time-frames
Super
cycle m
with 10k
Time-frames
(B)
TF2
1
100
0
beginning
of a UTC second
1
m
CTR (UTC)

FIG. 3

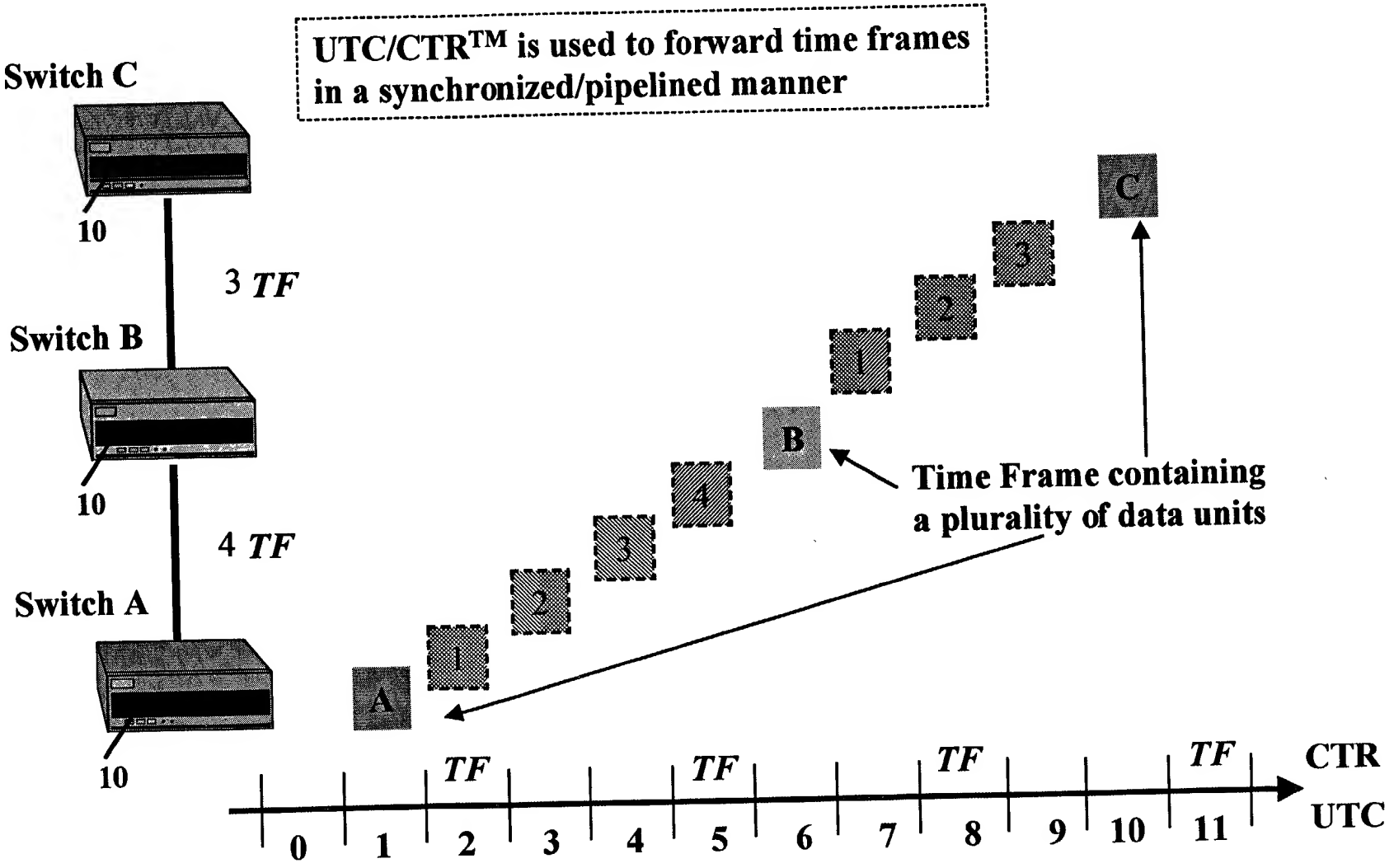

UTC/CTR™ is used to forward time frames in a synchronized/pipelined manner
Switch C
Switch B
Switch A
10
10
10
3 TF
4 TF
A
B
C
1
2
3
4
1
2
3
Time Frame containing a plurality of data units
TF
TF
TF
TF
CTR
UTC
0
1
2
3
4
5
6
7
8
9
10
11

FIG. 4

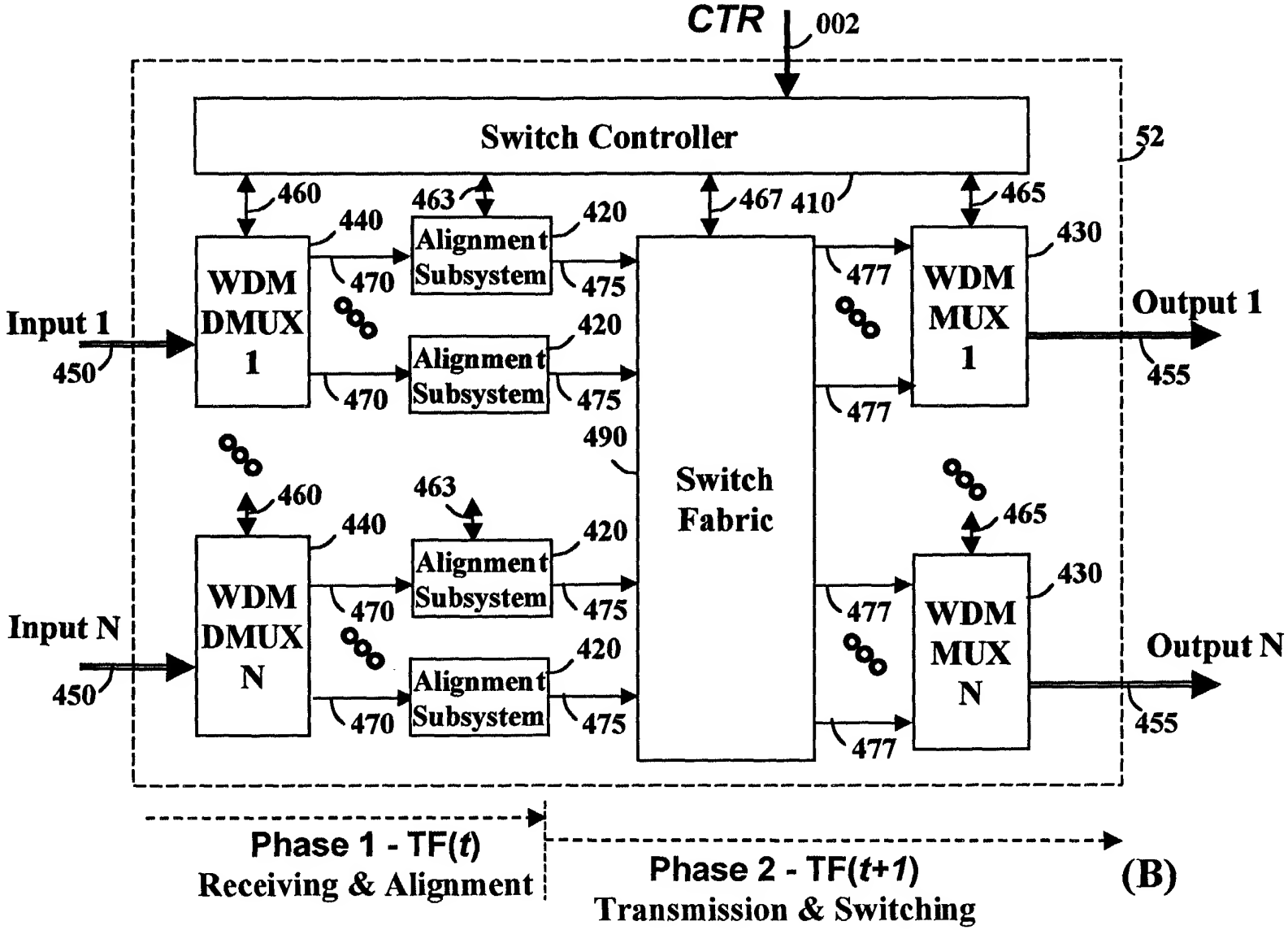


FIG. 5

Two time intervals: SC1_length·TF1 = 1 UTC second

- SC2_length·TF2 = 1 UTC second
- TF2 = (SC1_length / SC2_length) · TF1 = k · TF1, where the time cycles of TF1 and TF2 are aligned with respect to UTC.

For $k = 2$ and $c = 4$ (e.g., High_capacity=OC-192, Low_capacity=OC-48):

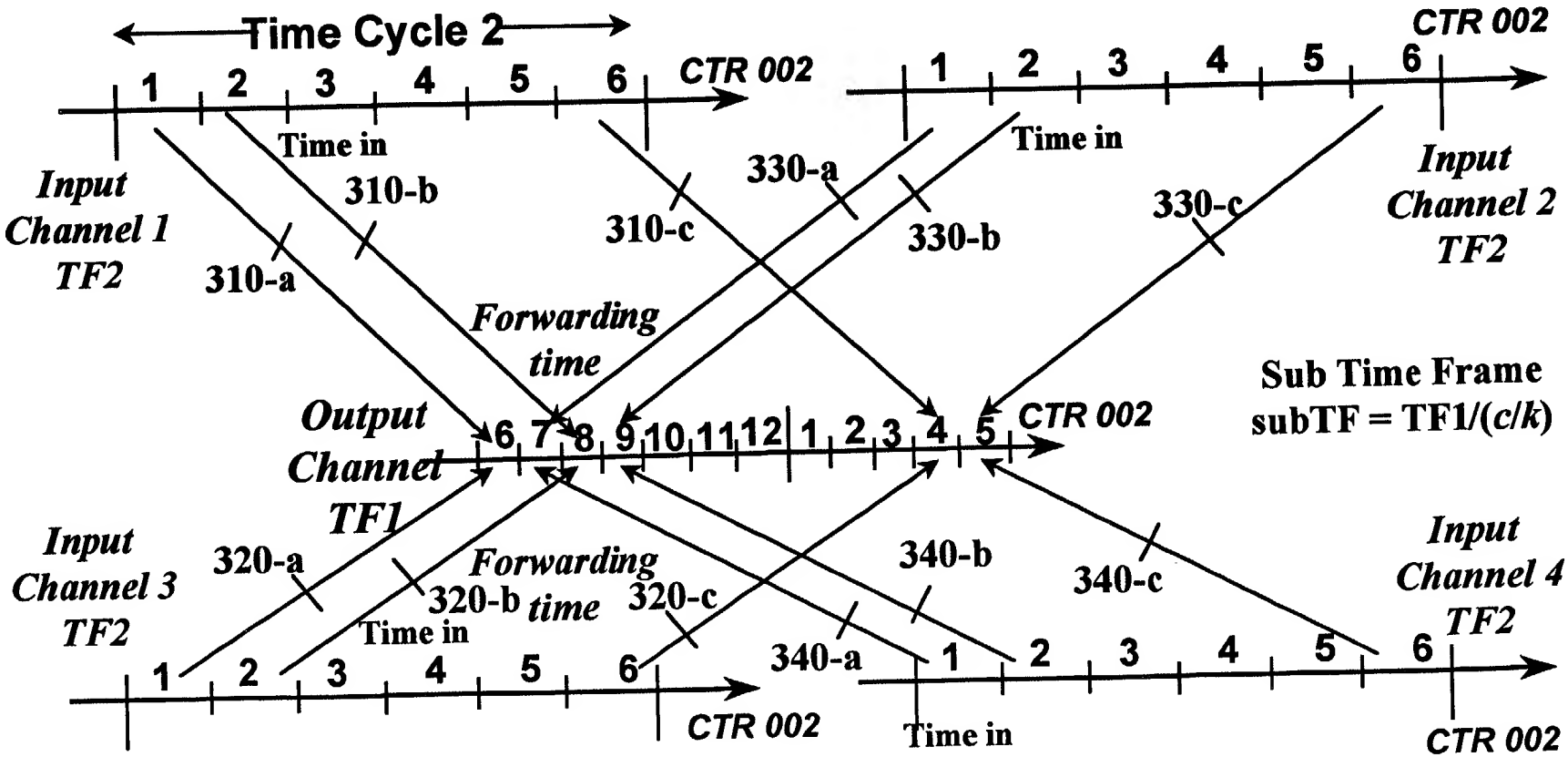


FIG. 6

Two time intervals: ***SC1_length·TF1 = 1*** **UTC second**

- ***SC2_length·TF2 = 1*** **UTC second**
- ***TF2 = (SC1_length / SC2_length) · TF1 = k · TF1***, where the time cycles of ***TF1*** and ***TF2*** are aligned with respect to UTC.

For $k = 2$ and $c = 4$ (e.g., High_capacity=OC-192, Low_capacity=OC-48):

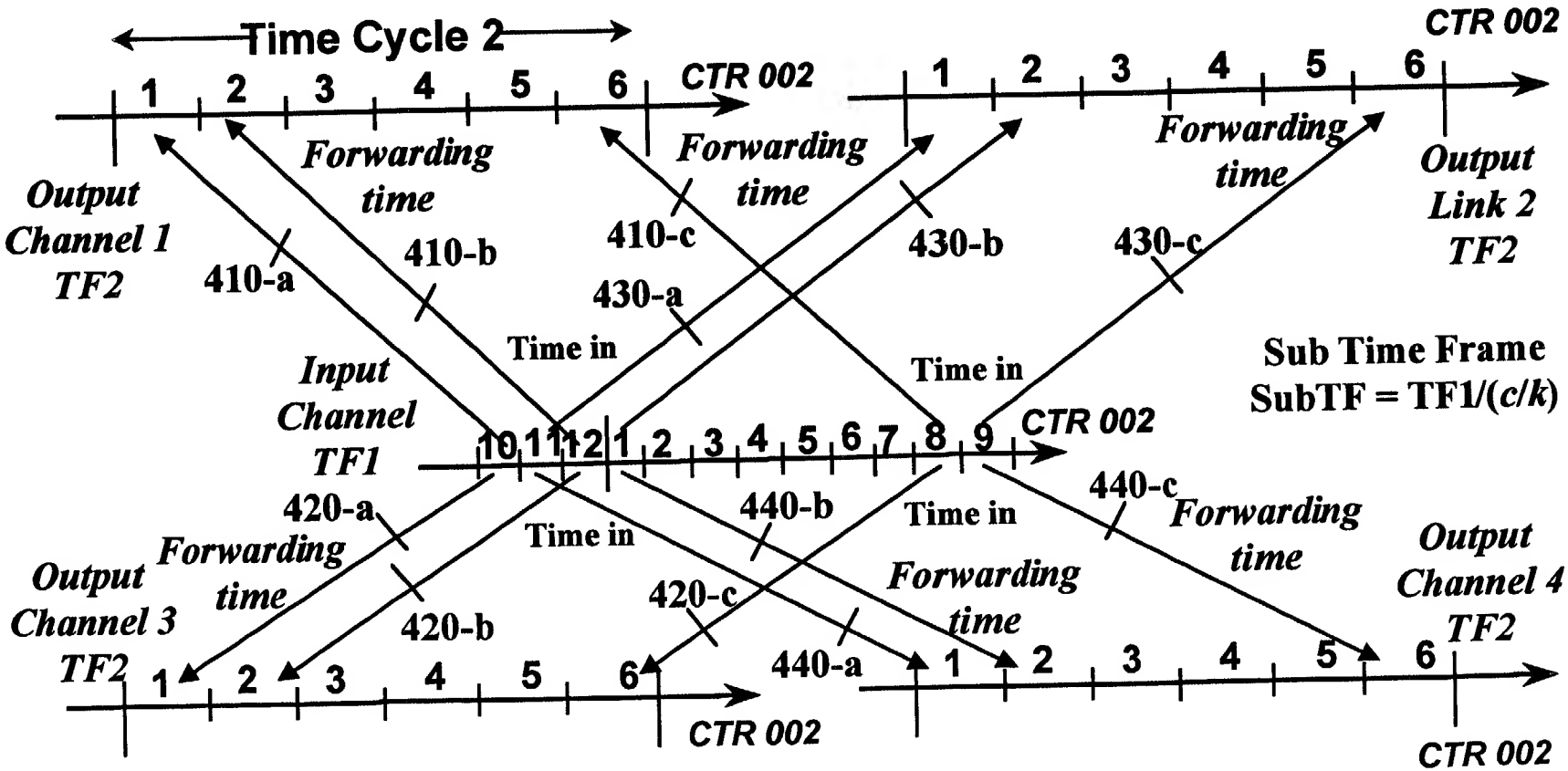


FIG. 7

Two time intervals: $SC1\_length \cdot TF1 = 1$ **UTC second**

- $SC2\_length \cdot TF2 = 1$ **UTC second**
- $TF2 = (SC1\_length / SC2\_length) \cdot TF1 = k \cdot TF1$, **where the time cycles of** $TF1$ **and** $TF2$ **are aligned with respect to UTC.**
  For $k = 2$ **and** $c = 4$ **(e.g., High_capacity=OC-192, Low_capacity=OC-48):**

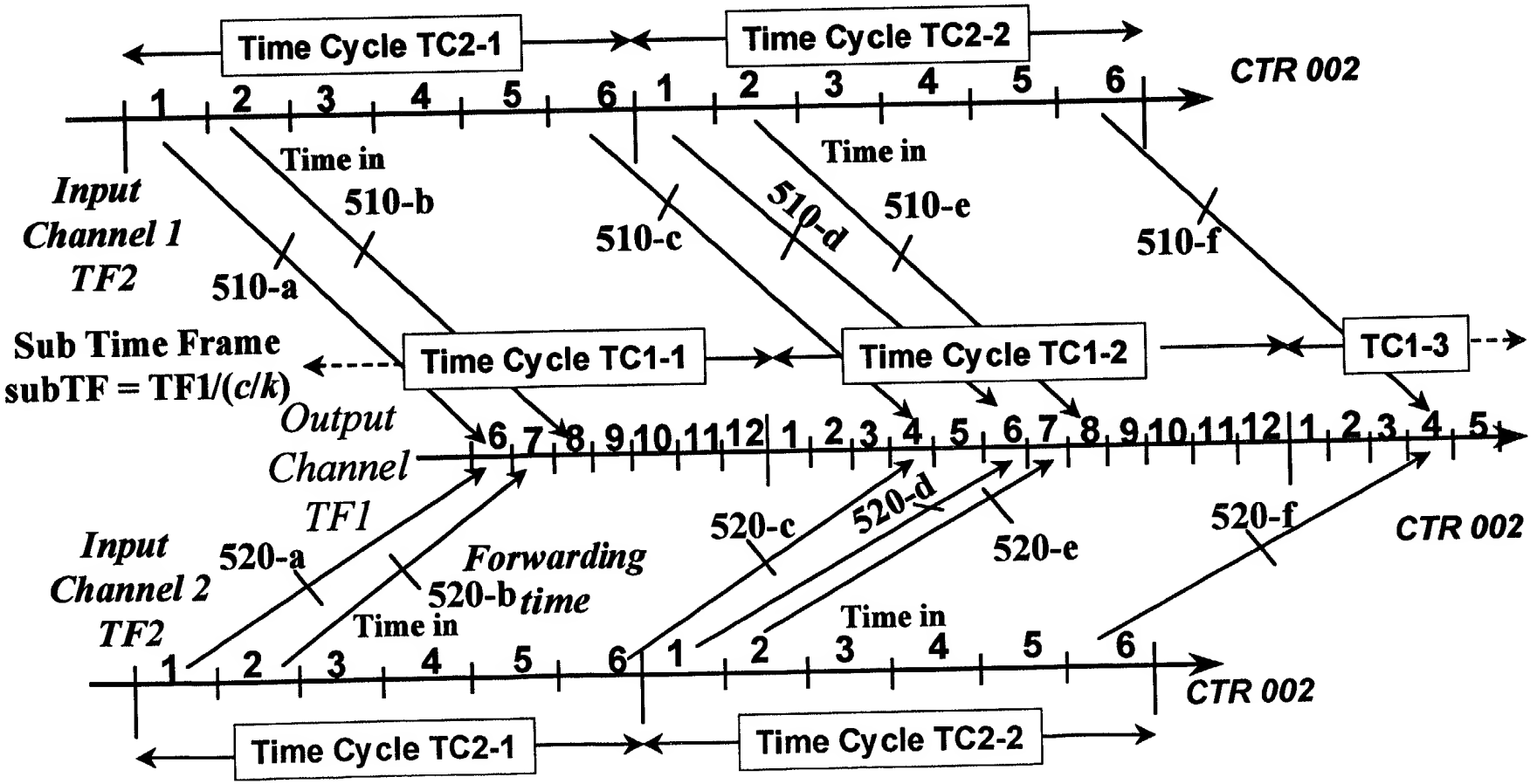


FIG. 8

Two time intervals: $SC1\_length \cdot TF1 = 1$ UTC second

- $SC2\_length \cdot TF2 = 1$ UTC second
- $TF2 = (SC1\_length / SC2\_length) \cdot TF1 = k \cdot TF1$, where the time cycles of $TF1$ and $TF2$ are aligned with respect to UTC.

For $k = 2$ and $c = 4$ (e.g., High_capacity=OC-192, Low_capacity=OC-48):

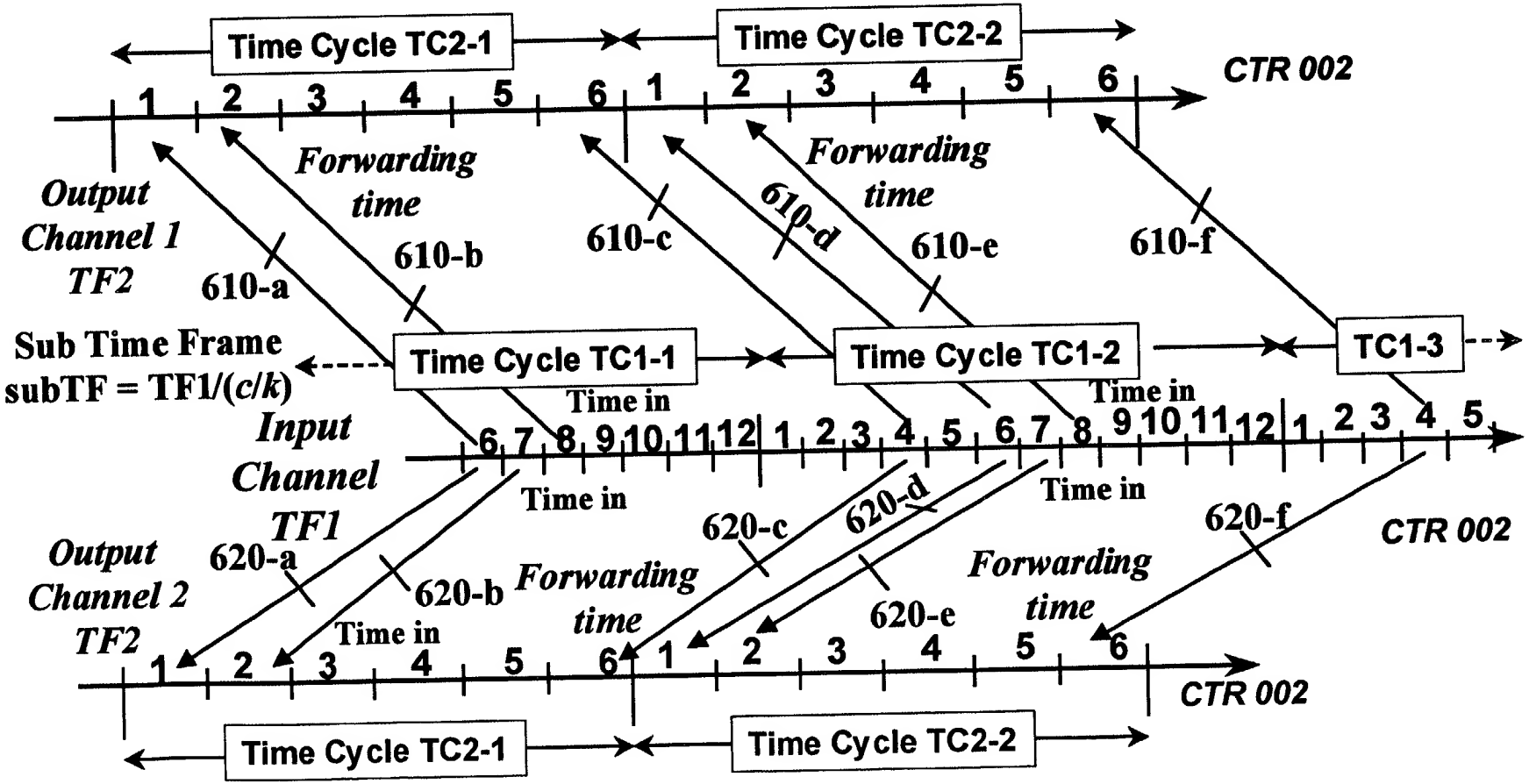


FIG. 9

c=4, e.g., OC-192/OC-48
k=2, e.g., 25 microsec/12.5 microsec

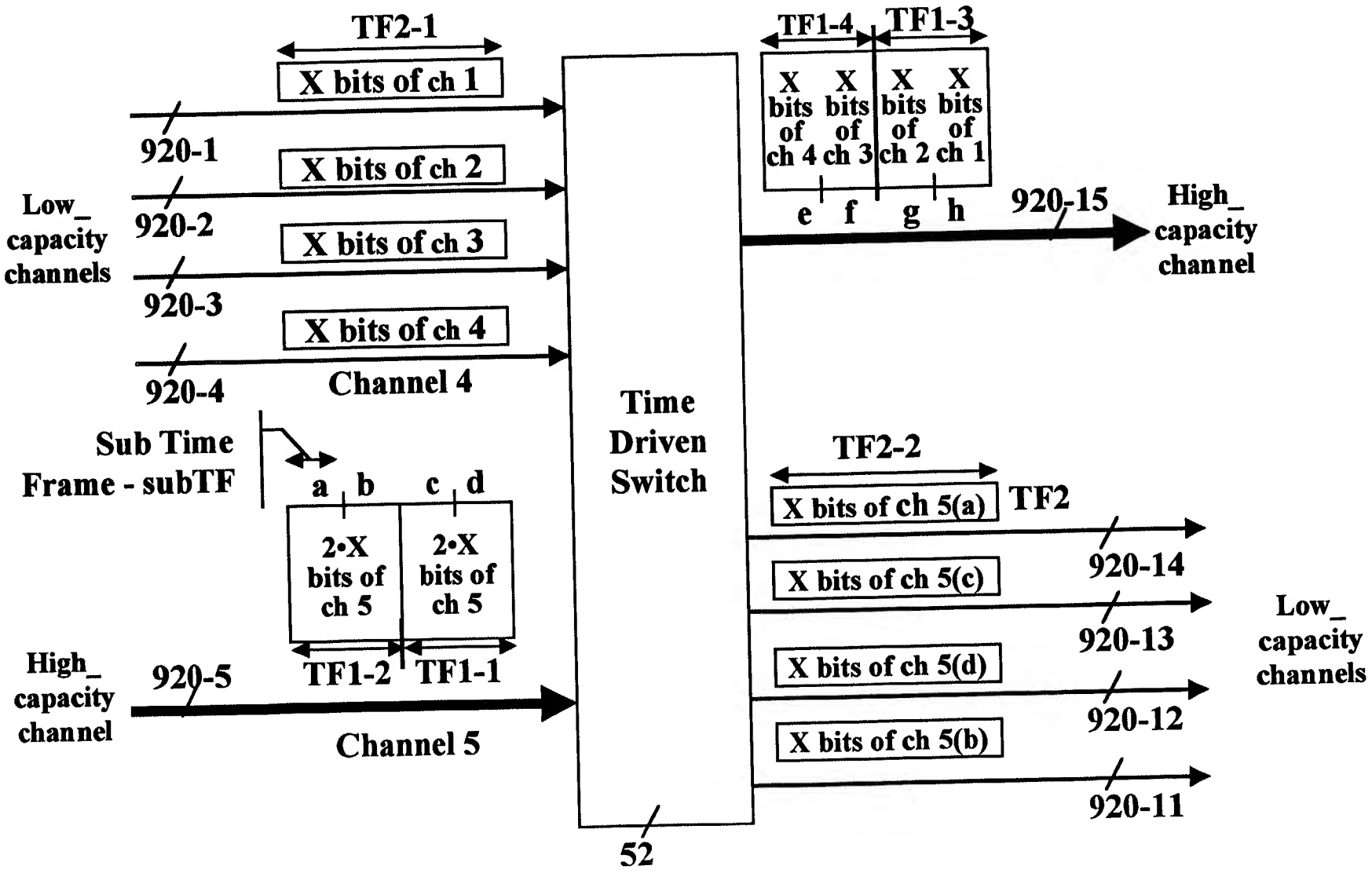


FIG. 10

c=4, e.g., OC-192/OC-48
k=2, e.g., 25 microsec/12.5 microsec

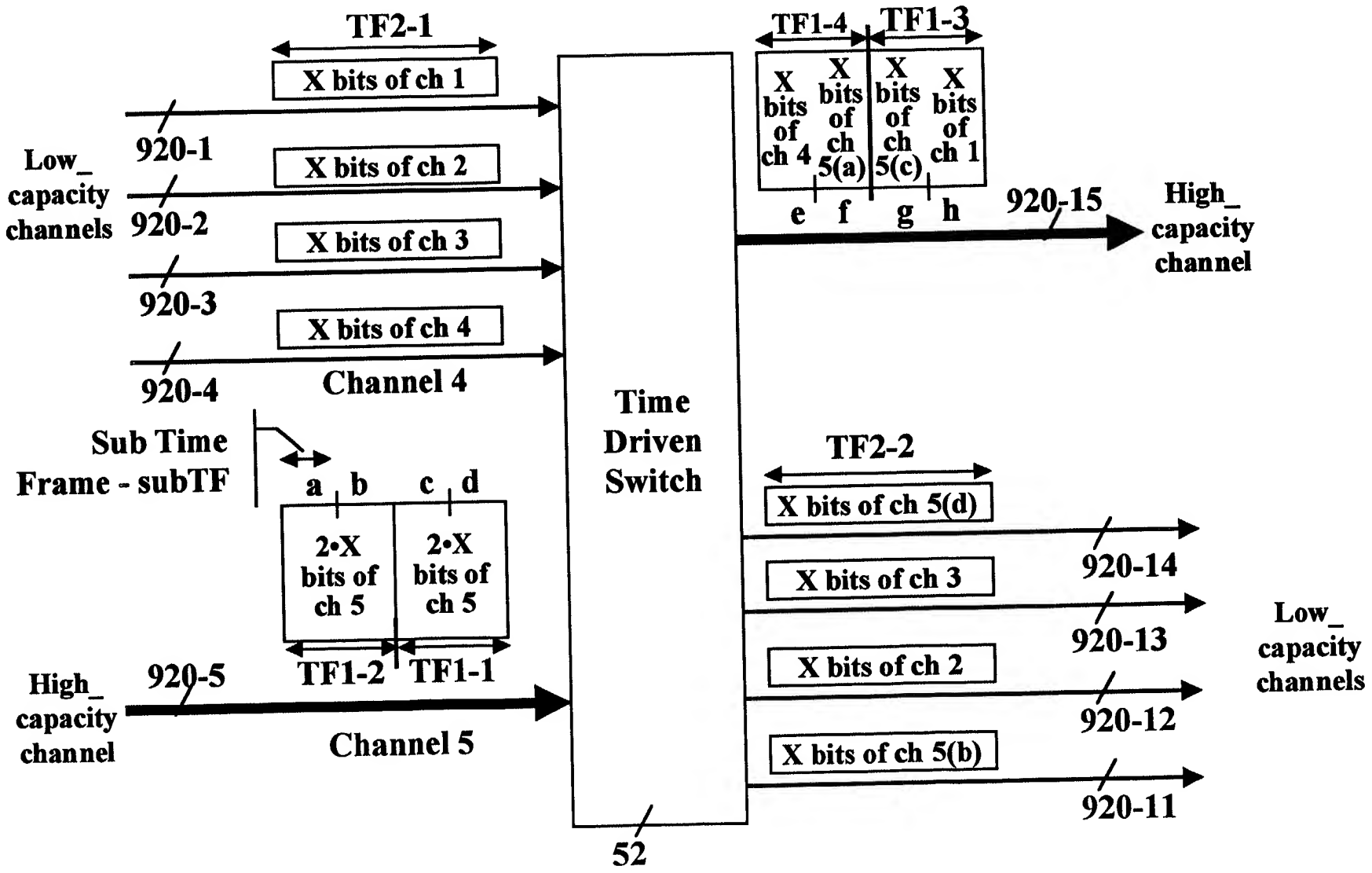


FIG. 11

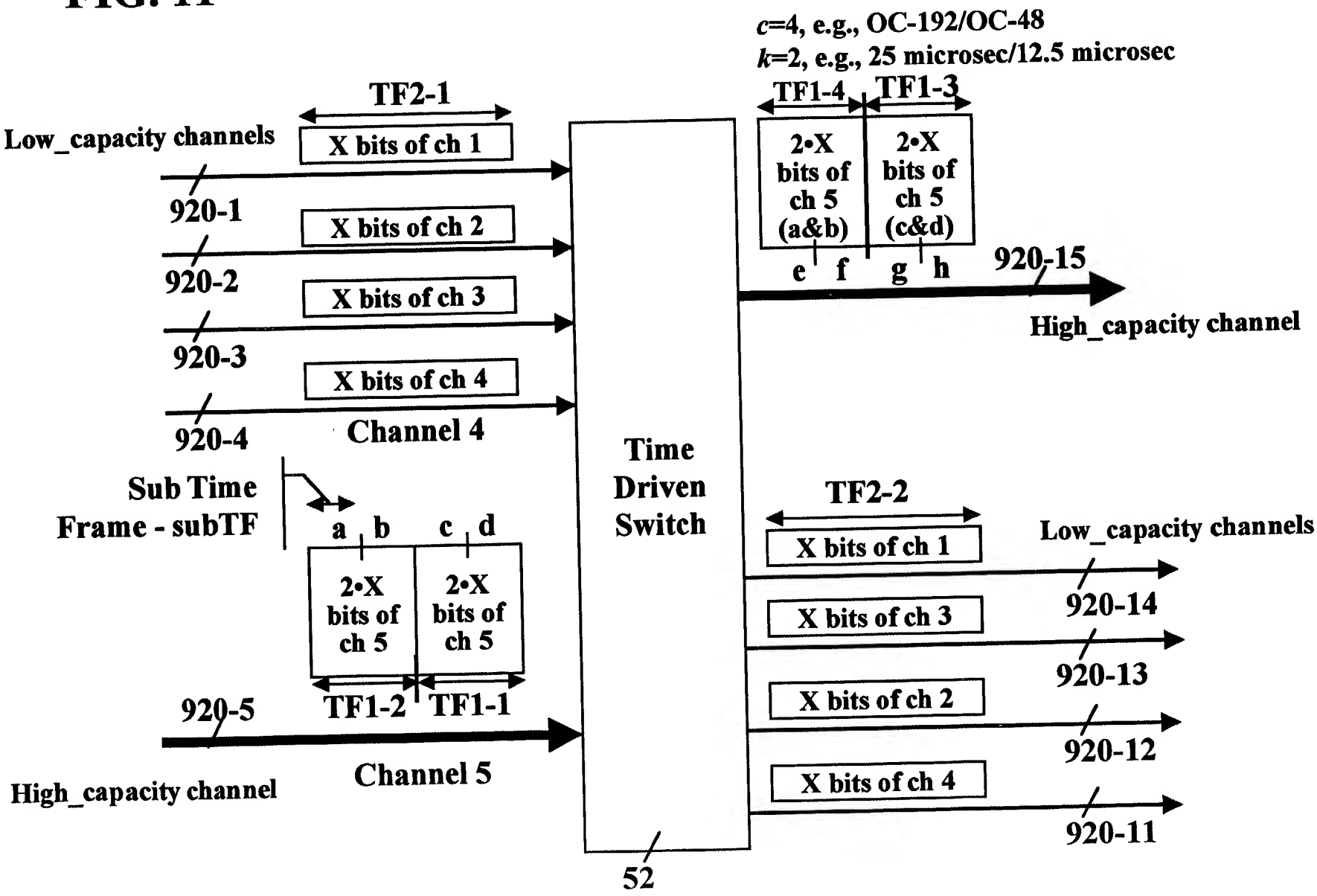


FIG. 12

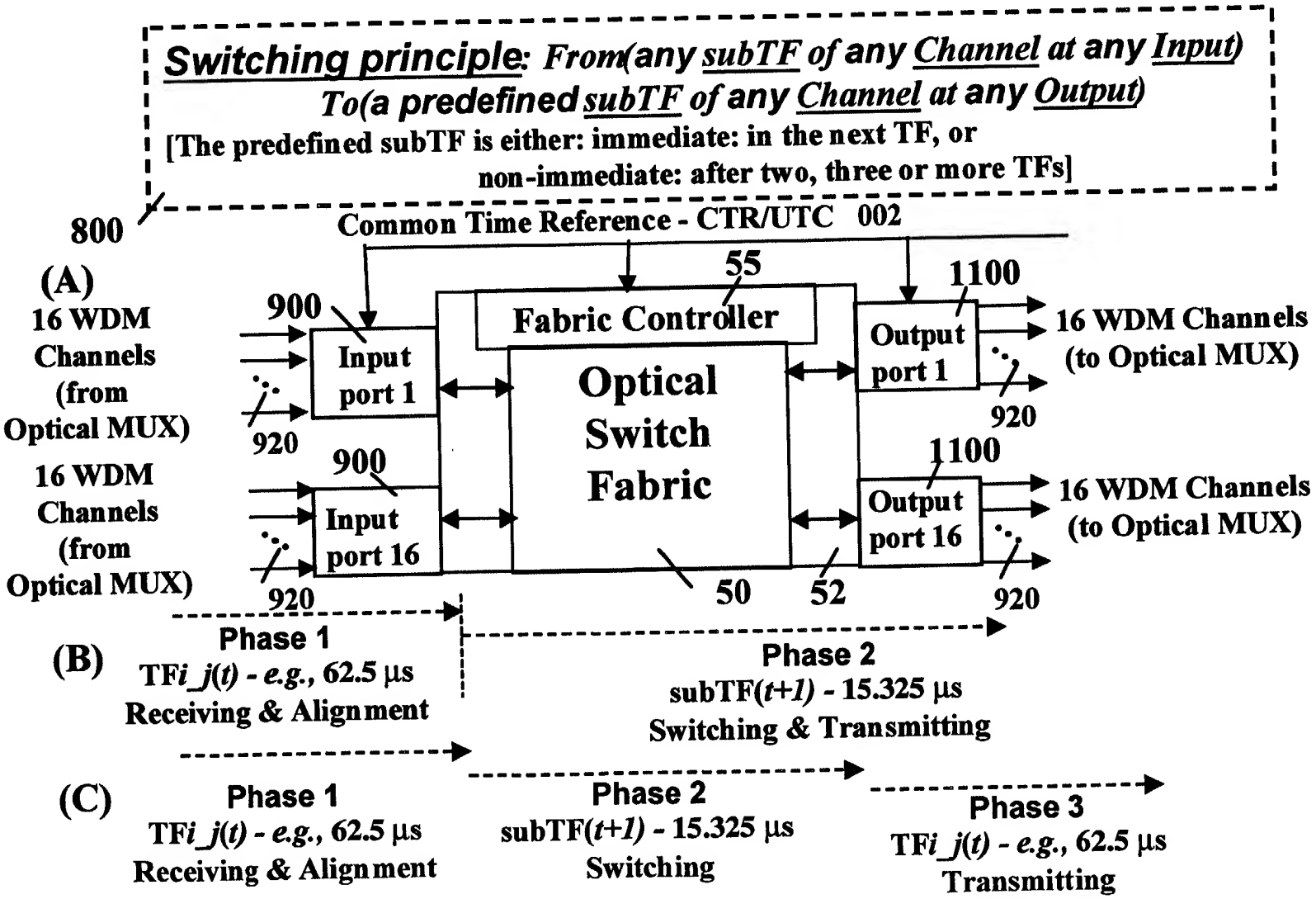

Switching principle: From(any subTF of any Channel at any Input)
To(a predefined subTF of any Channel at any Output)
[The predefined subTF is either: immediate: in the next TF, or
non-immediate: after two, three or more TFs]
800
Common Time Reference - CTR/UTC 002
(A)
16 WDM Channels (from Optical MUX)
16 WDM Channels (from Optical MUX)
900
900
Input port 1
Input port 16
920
920
55
Fabric Controller
Optical Switch Fabric
50
52
1100
1100
Output port 1
Output port 16
920
920
16 WDM Channels (to Optical MUX)
16 WDM Channels (to Optical MUX)
(B)
Phase 1
TFi_j(t) - e.g., 62.5 µs
Receiving & Alignment
Phase 2
subTF(t+1) - 15.325 µs
Switching & Transmitting
(C)
Phase 1
TFi_j(t) - e.g., 62.5 µs
Receiving & Alignment
Phase 2
subTF(t+1) - 15.325 µs
Switching
Phase 3
TFi_j(t) - e.g., 62.5 µs
Transmitting

FIG. 13

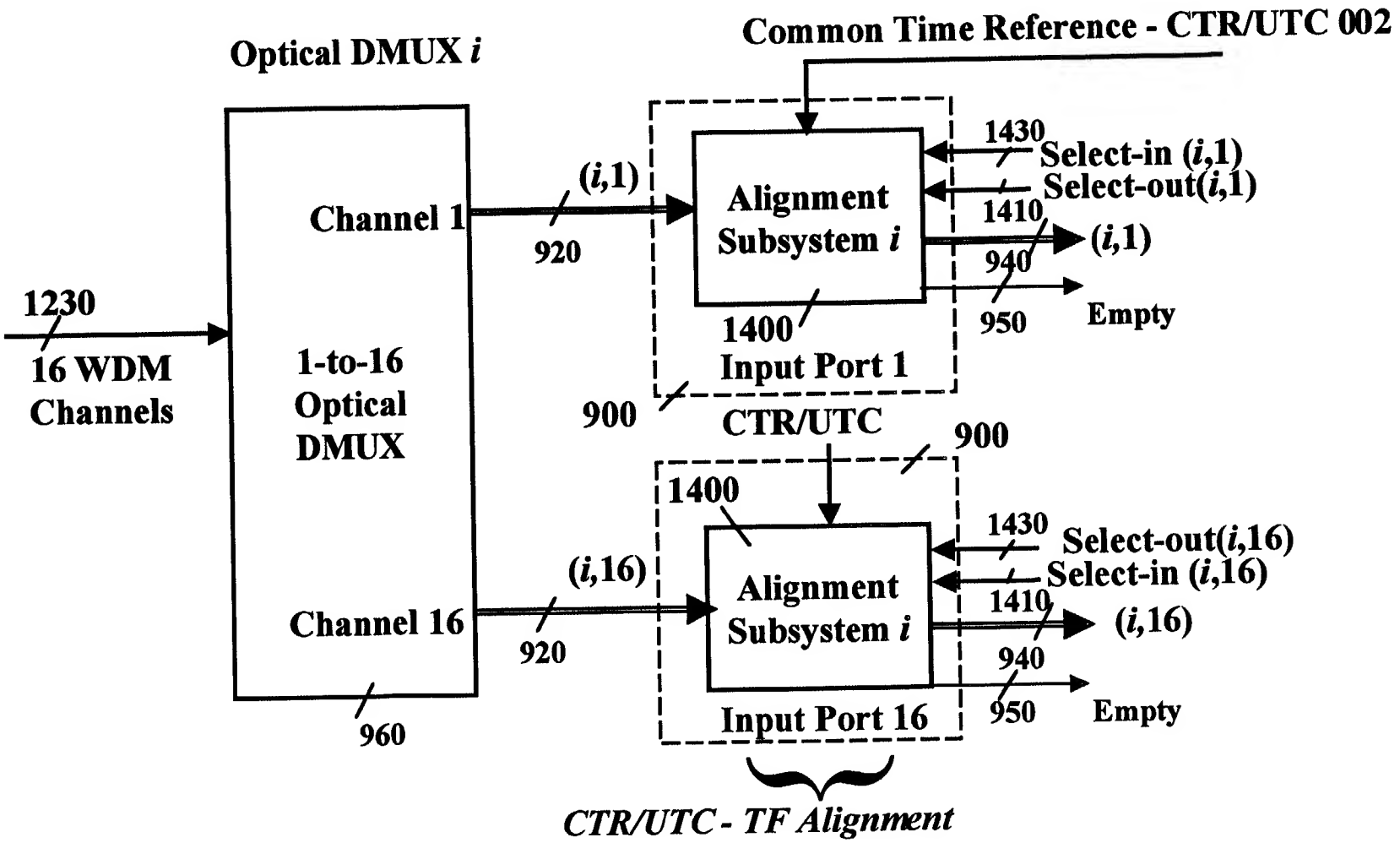


FIG. 14

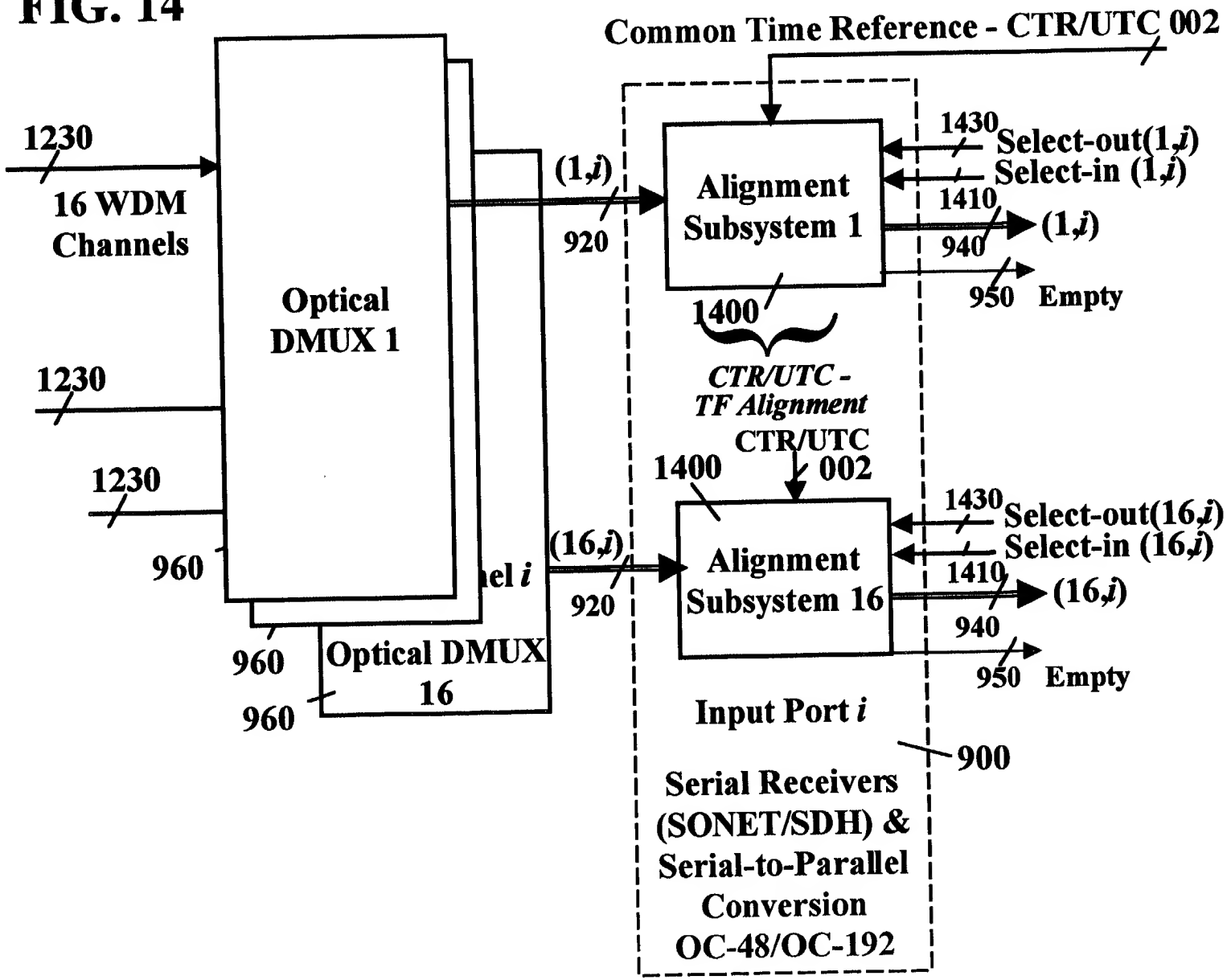


FIG. 15

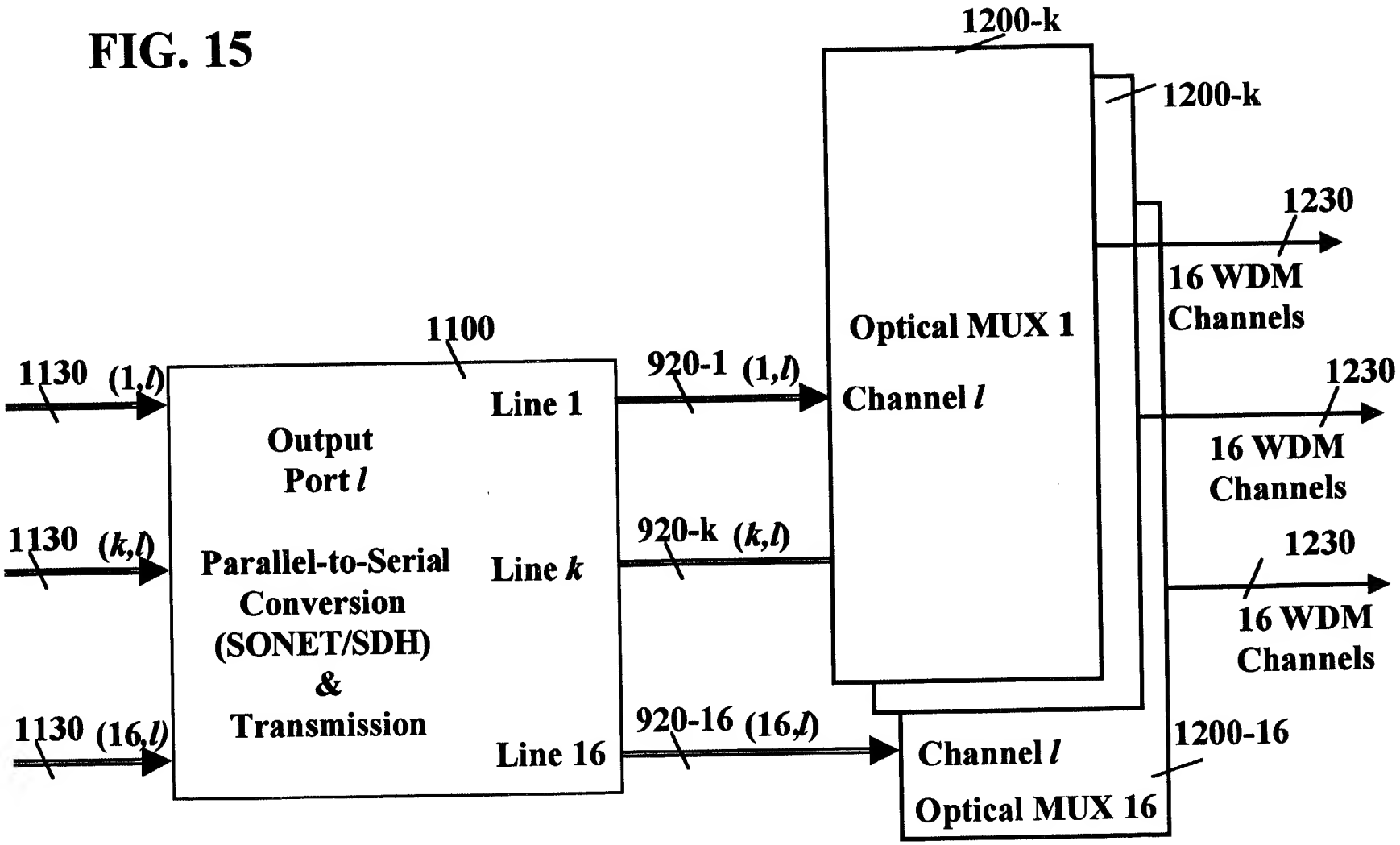


FIG. 16

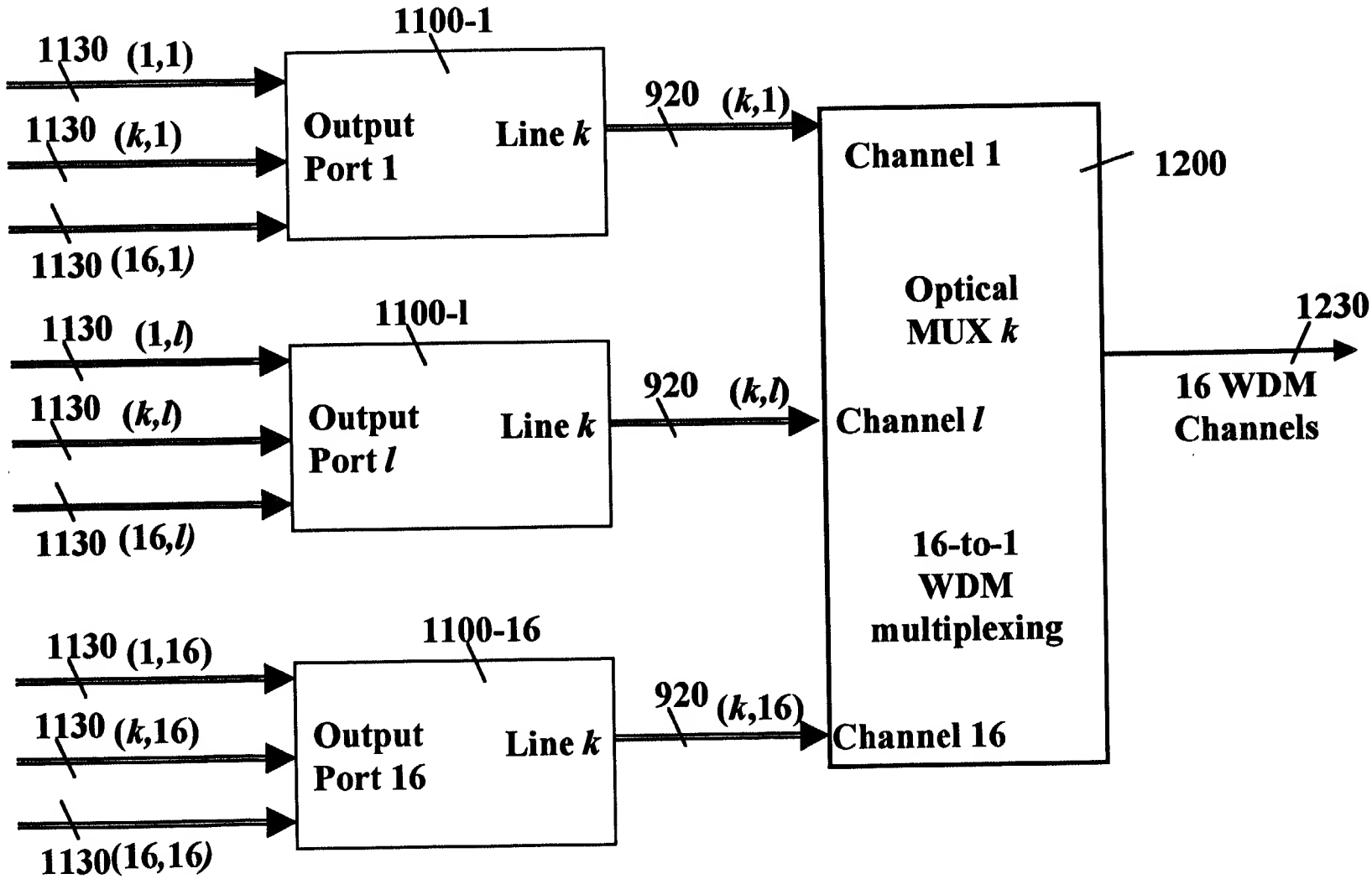


FIG. 17

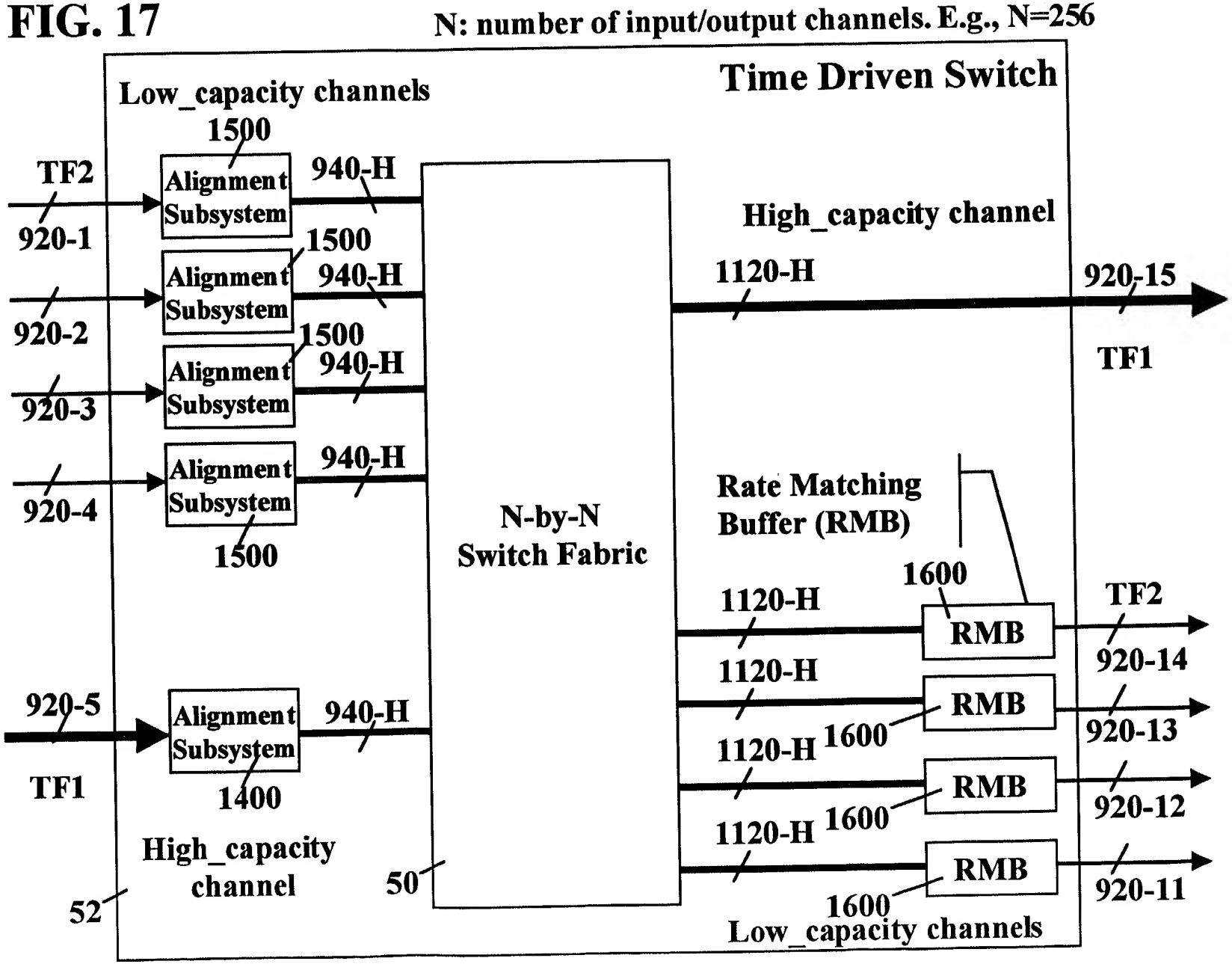


FIG. 18

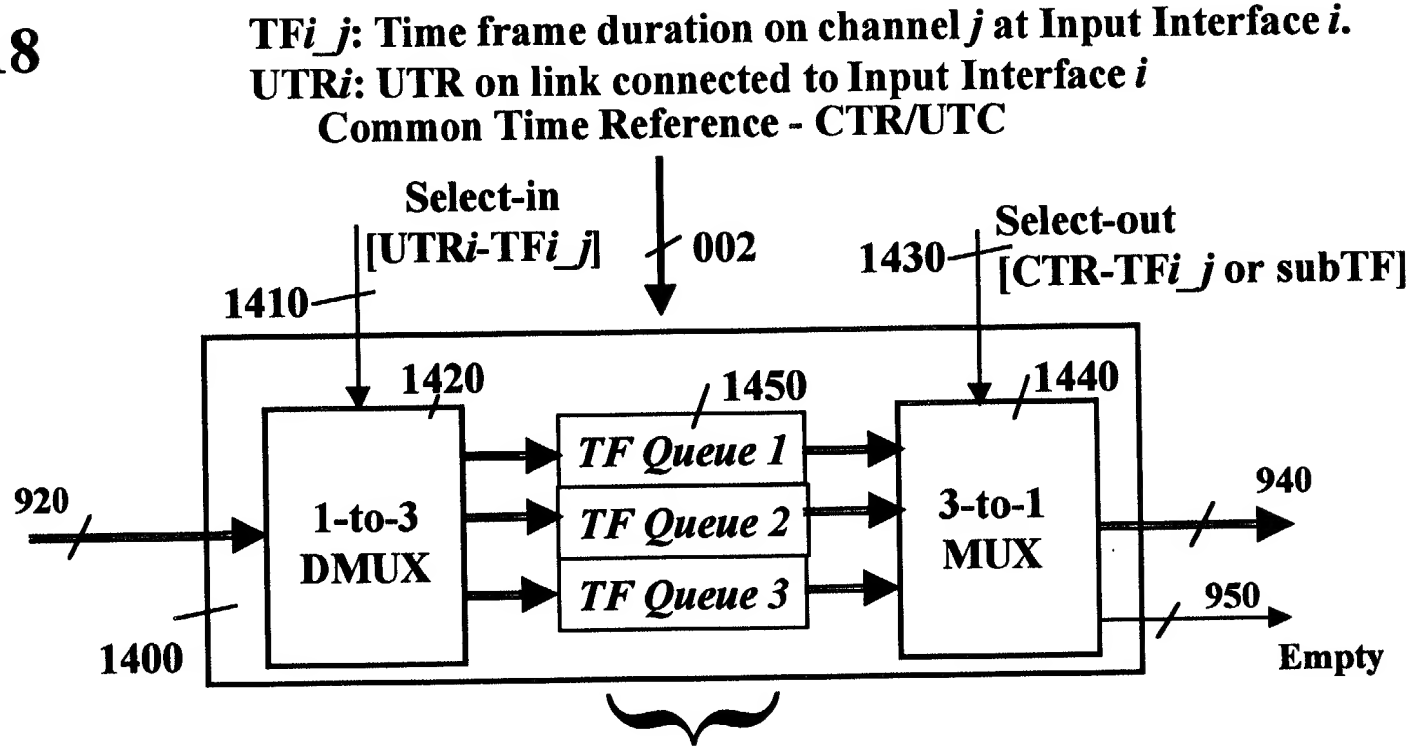
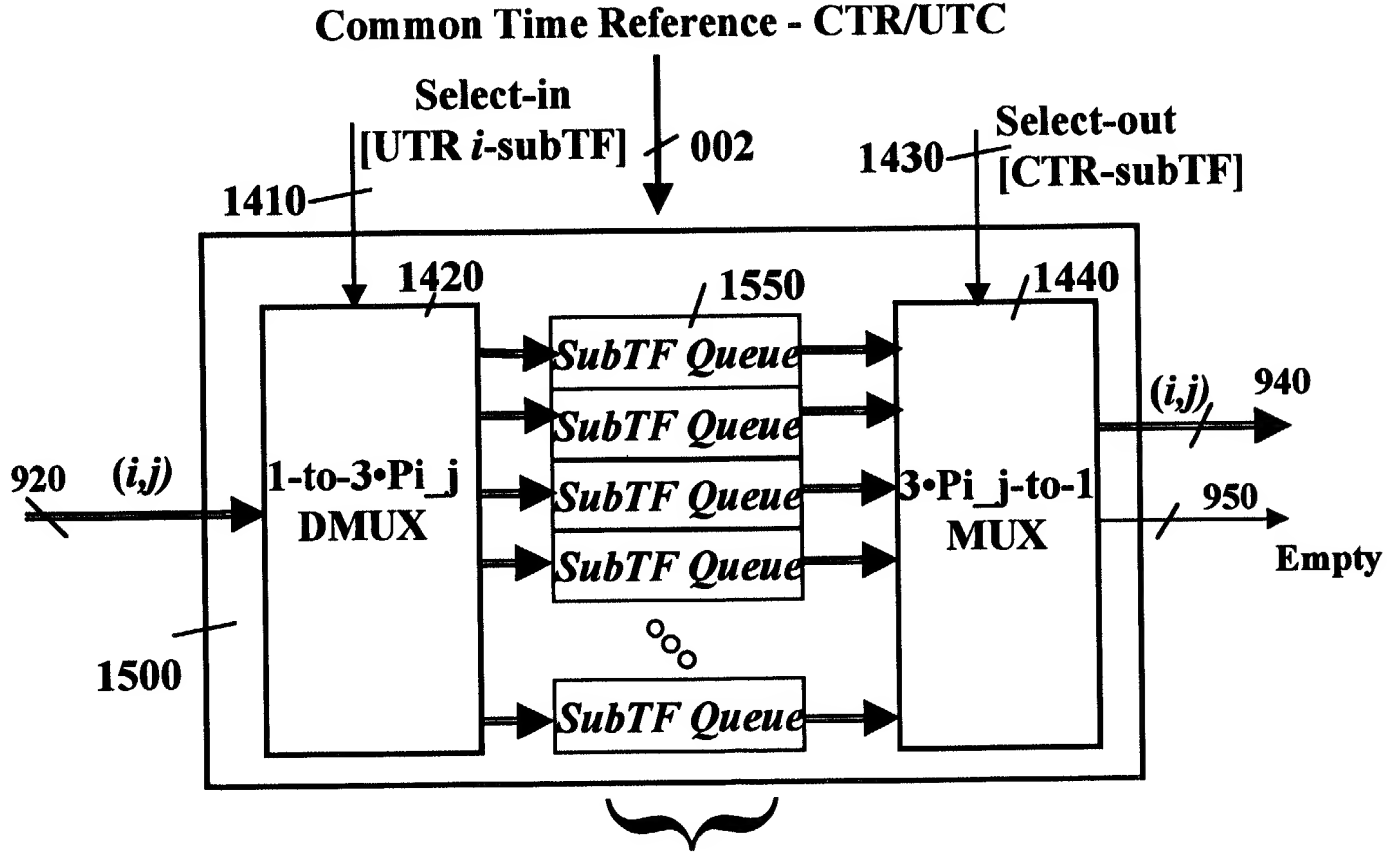


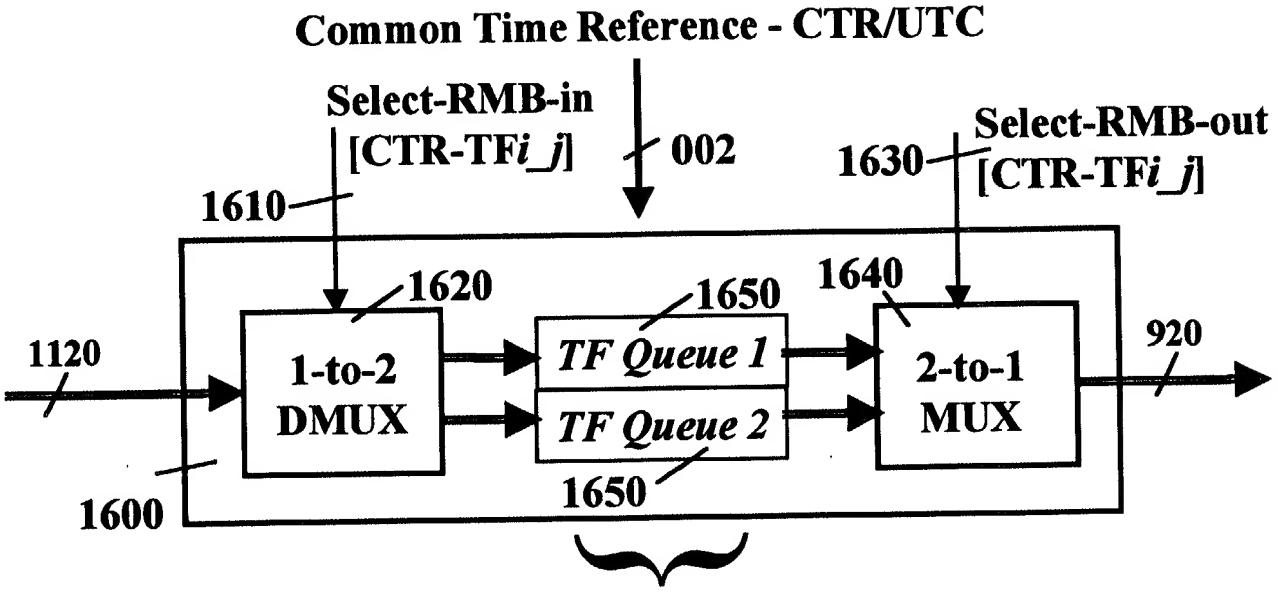
FIG. 19

TF*i_j*: Time frame duration on channel *j* at Input Interface *i*.
UTR *i*: UTR on link connected to Input Interface *i*
P*i_j* = TF*i_j*/subTF



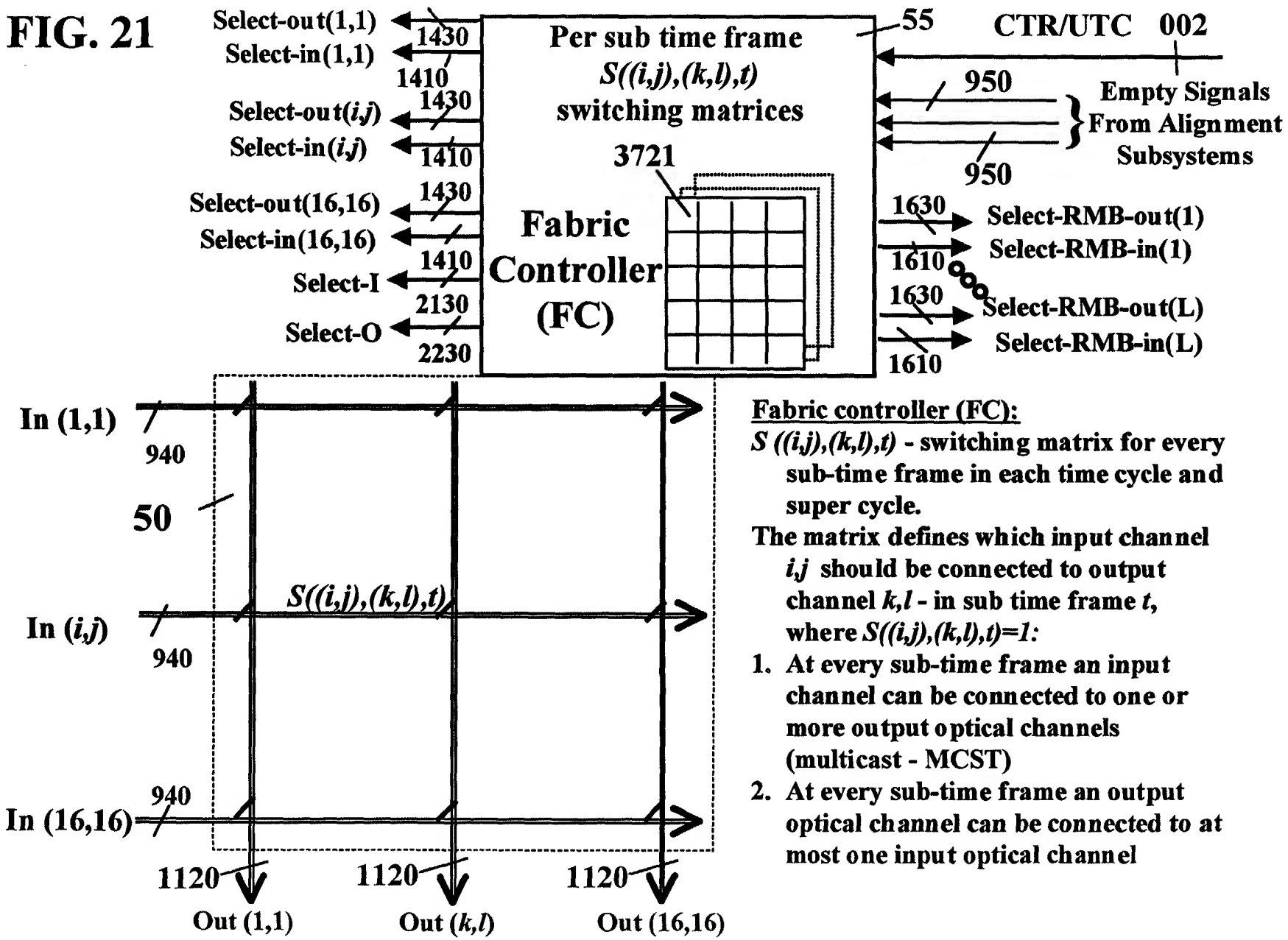
Alignment Subsystem for *high capacity* Channel *j* at Input Interface *i*
with a Plurality of Sub-Time Frame Queues

FIG. 18+2 TF*i_j*: Time frame duration on channel *j* at Input Interface *i*.
UTR*i*: UTR on link connected to Input Interface *i*



Rate Matching Buffer for Channel *j* at Output Interface *i*
with a Plurality of Time Frame Queues
(Also single buffer with dual access memory with single phase switching and forwarding)

FIG. 21



Fabric controller (FC):

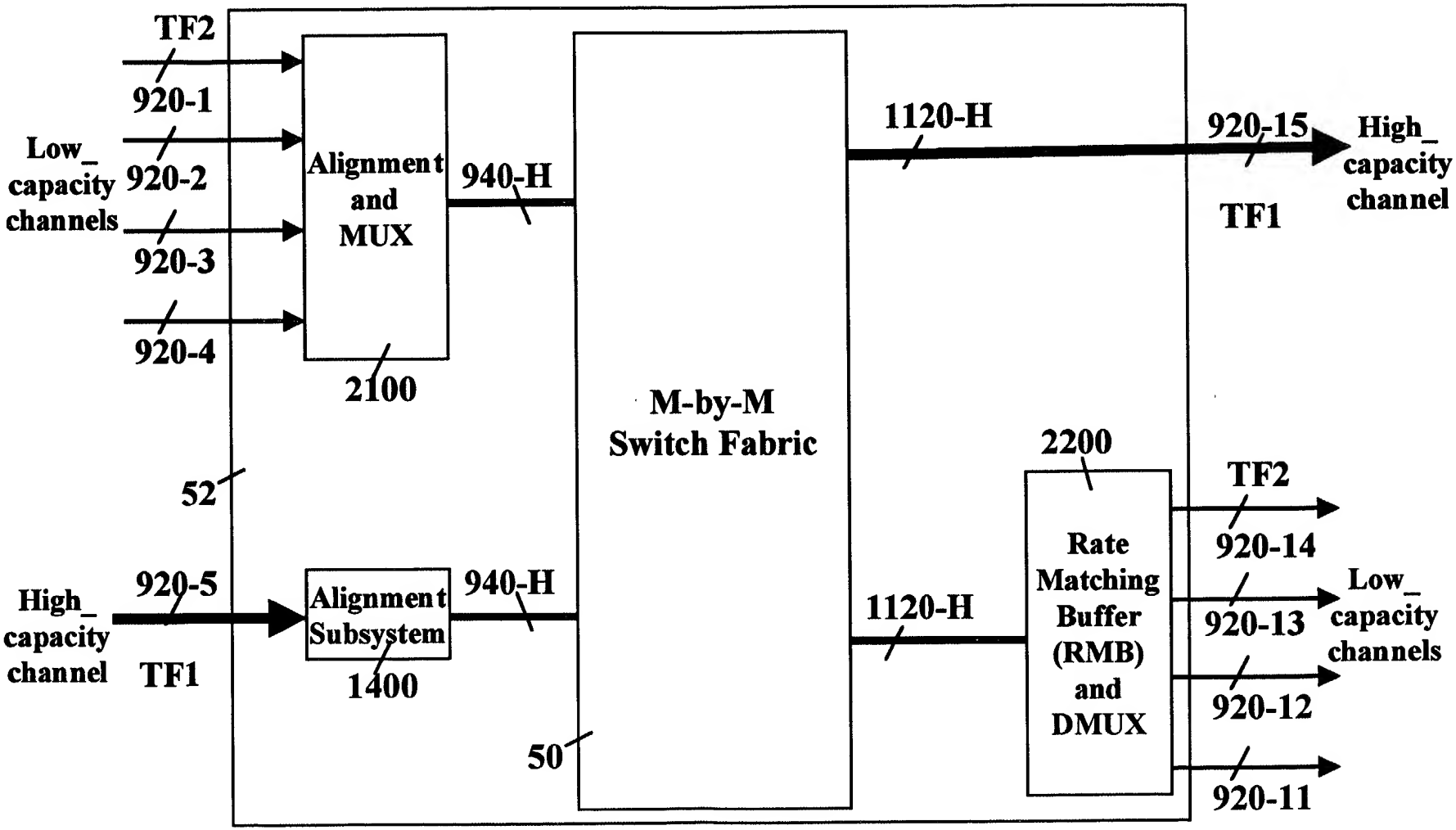
S ((i,j),(k,l),t) **- switching matrix for every sub-time frame in each time cycle and super cycle.**

The matrix defines which input channel *i,j* should be connected to output channel *k,l* - in sub time frame *t*, where *S((i,j),(k,l),t)=1:*

1. **At every sub-time frame an input channel can be connected to one or more output optical channels (multicast - MCST)**
2. **At every sub-time frame an output optical channel can be connected to at most one input optical channel**

FIG. 22

N: number of input/output channels. E.g., N=256
M • High_capacity = N_high • High_capacity + N_low • Low_capacity
M<N



Time Driven Switch

FIG. 23

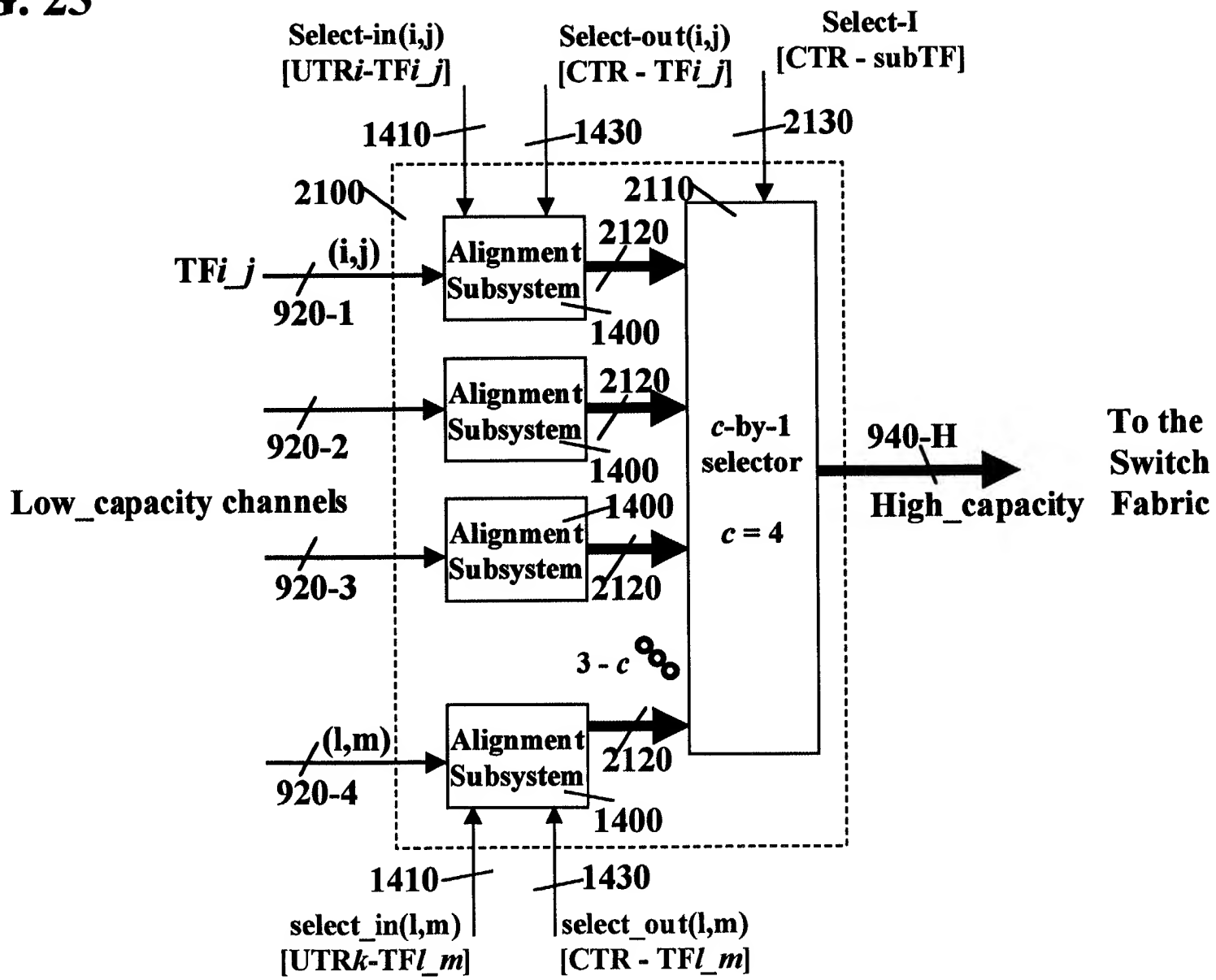


FIG. 24

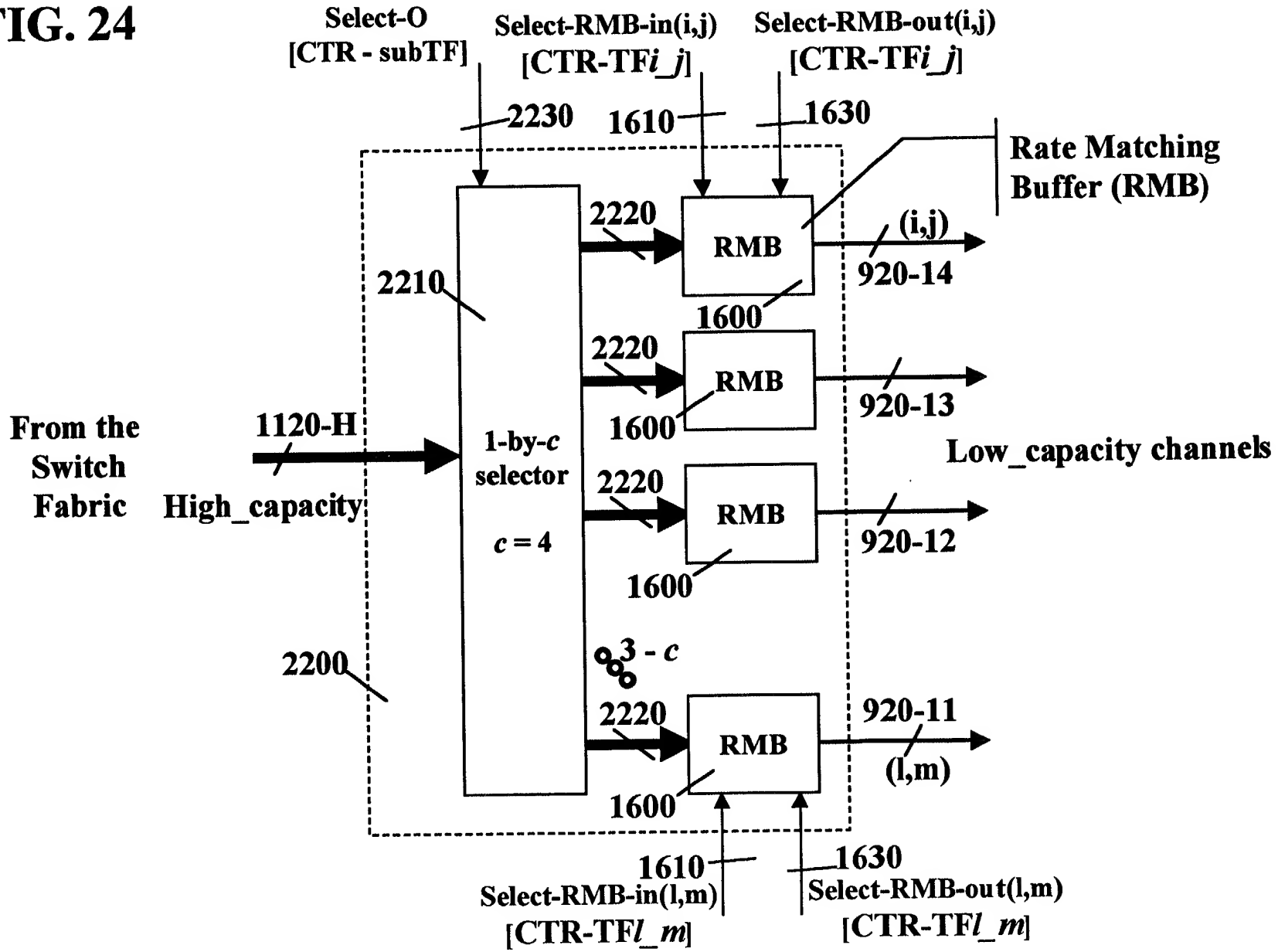
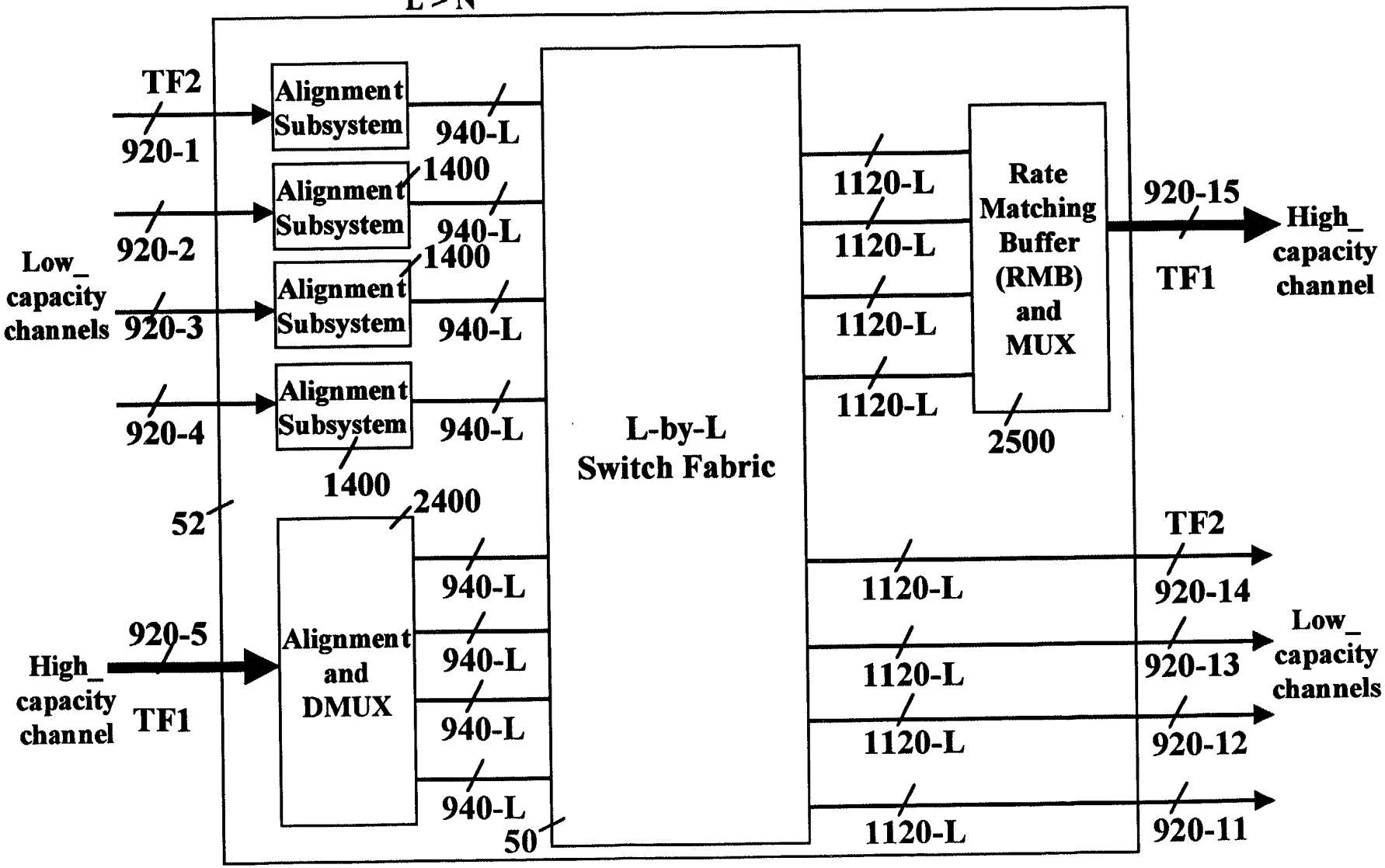

Select-O
[CTR - subTF]
Select-RMB-in(i,j)
[CTR-TFi_j]
Select-RMB-out(i,j)
[CTR-TFi_j]
2230
1610
1630
Rate Matching
Buffer (RMB)
2220
RMB
(i,j)
920-14
2210
1600
2220
RMB
920-13
From the
Switch
Fabric
1120-H
1-by-c
selector
c = 4
High_capacity
1600
Low_capacity channels
2220
RMB
920-12
1600
2200
3 - c
2220
RMB
920-11
(l,m)
1600
1610
Select-RMB-in(l,m)
[CTR-TFl_m]
1630
Select-RMB-out(l,m)
[CTR-TFl_m]

FIG. 25

N: number of input/output channels. E.g., N=256
L • Low_capacity = N_high • High_capacity + N_low • Low_capacity
L > N



Time Driven Switch

FIG. 26

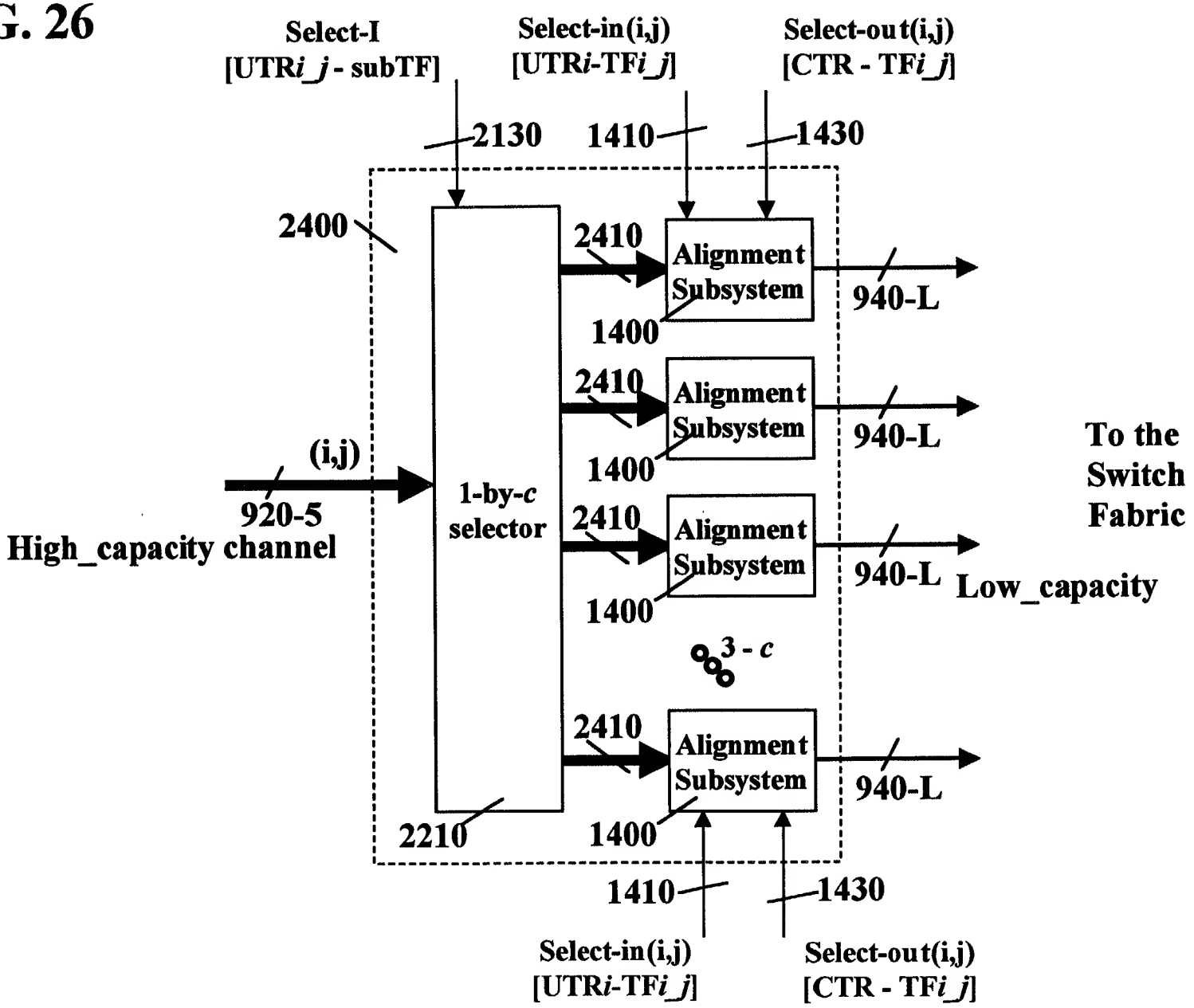

Select-I
[UTRi_j - subTF]
Select-in(i,j)
[UTRi-TFi_j]
Select-out(i,j)
[CTR - TFi_j]
2130
1410
1430
2400
2410
Alignment Subsystem
940-L
1400
(i,j)
920-5
High_capacity channel
1-by-c selector
To the Switch Fabric
Low_capacity
3 - c
2210

FIG. 27

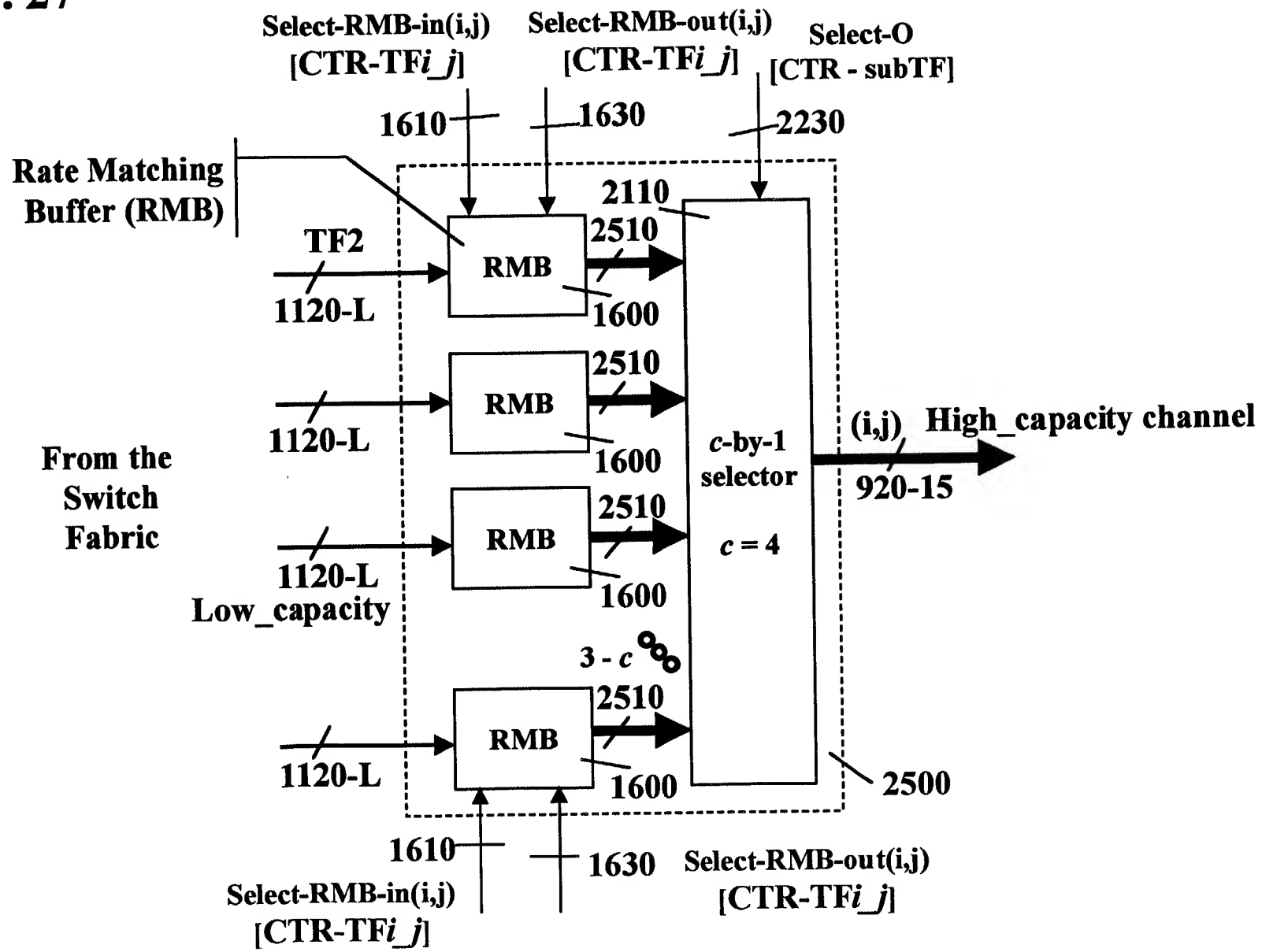
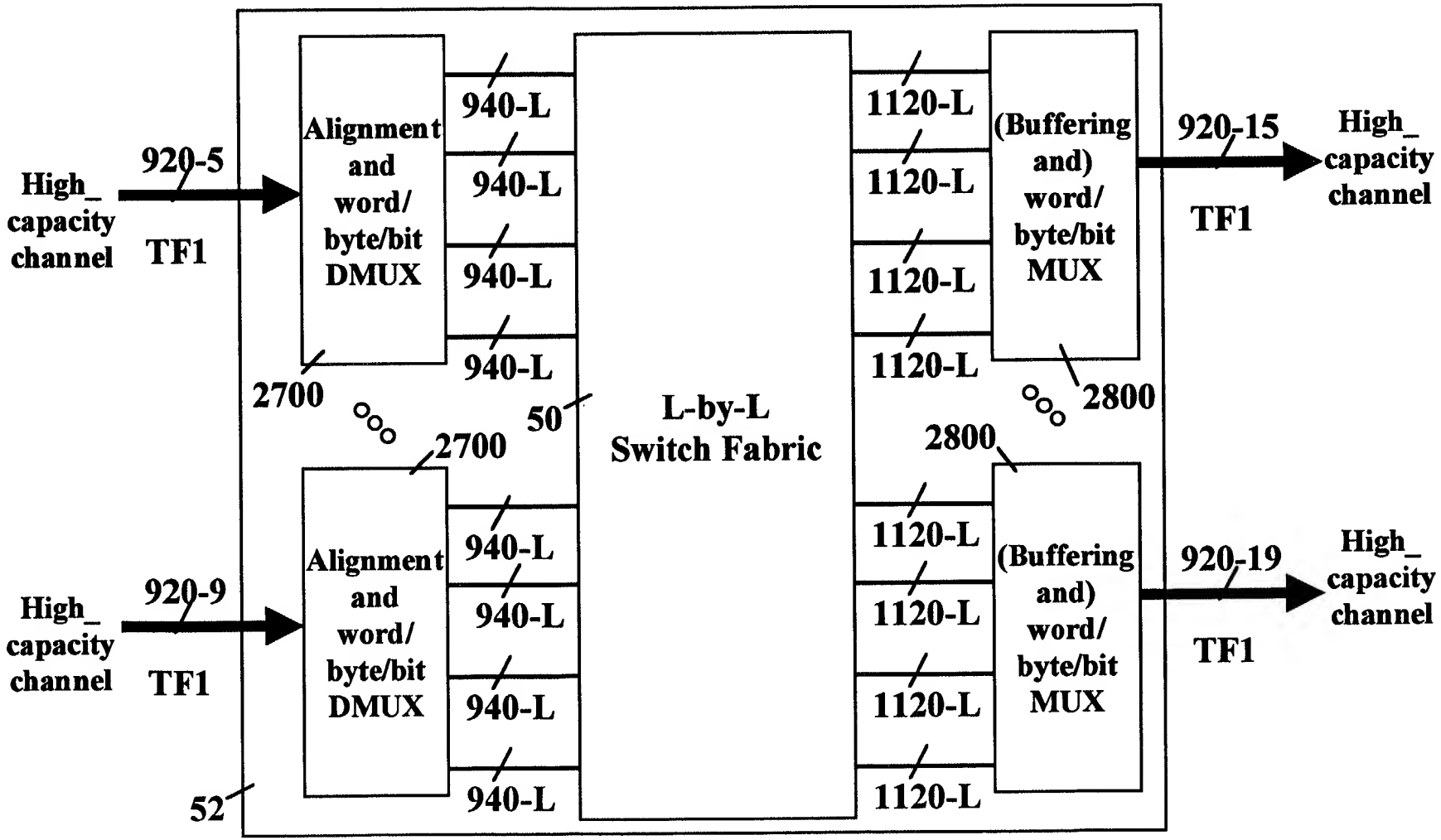


FIG. 28

N: number of input/output channels. E.g., N=256
L • Low_capacity = N • High_capacity
L = c • N > N



Time Driven Switch

FIG. 29

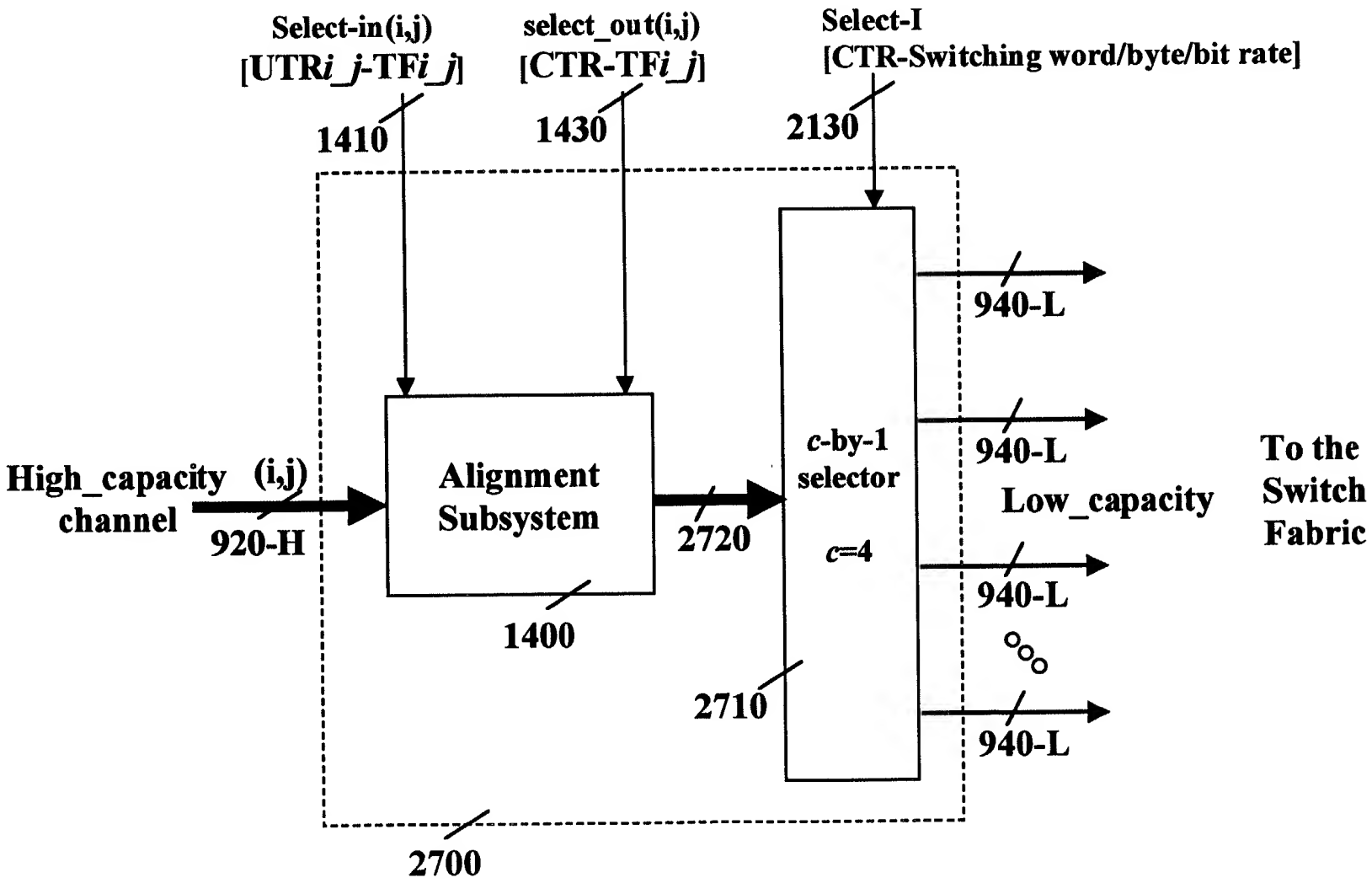


FIG. 30

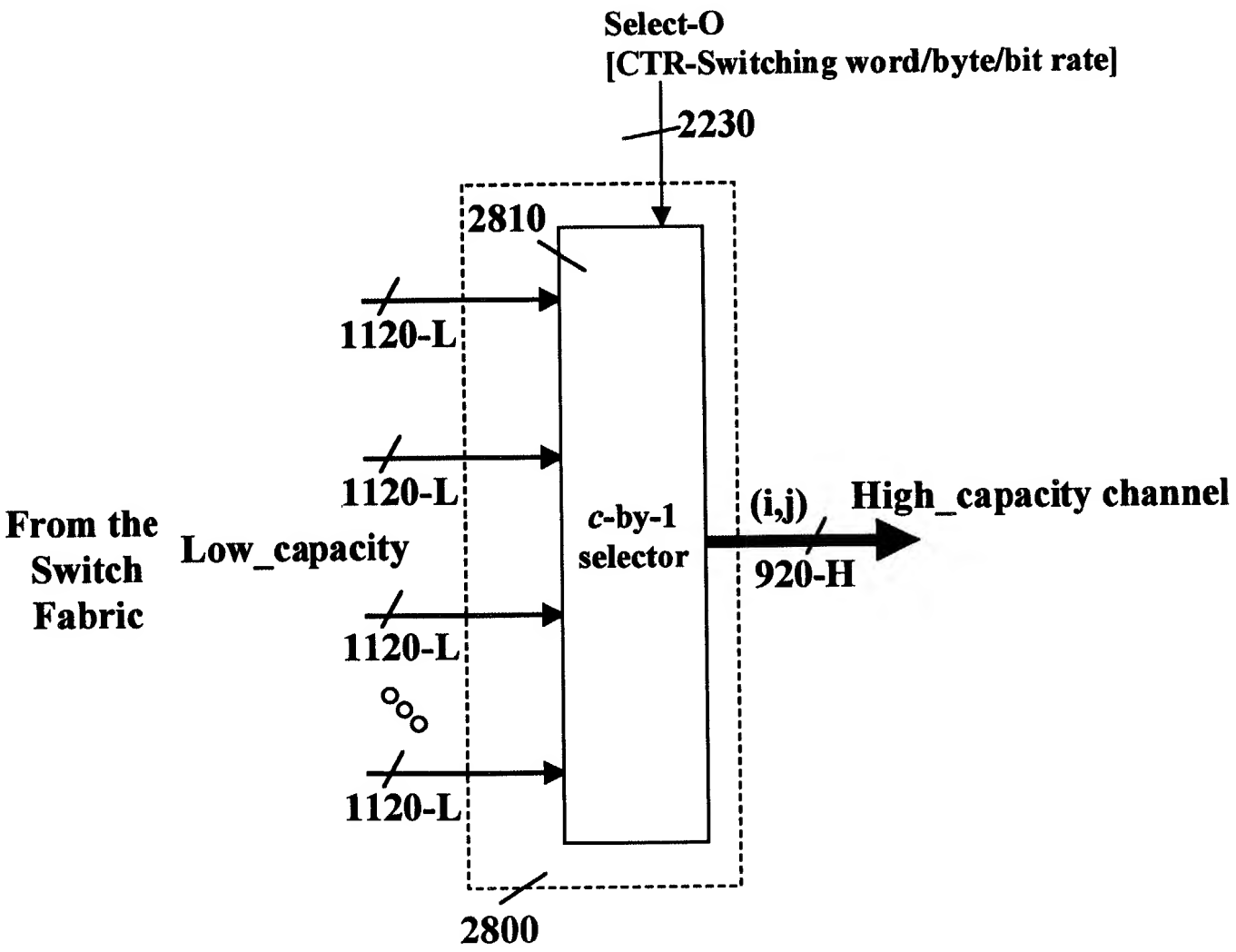


FIG. 31

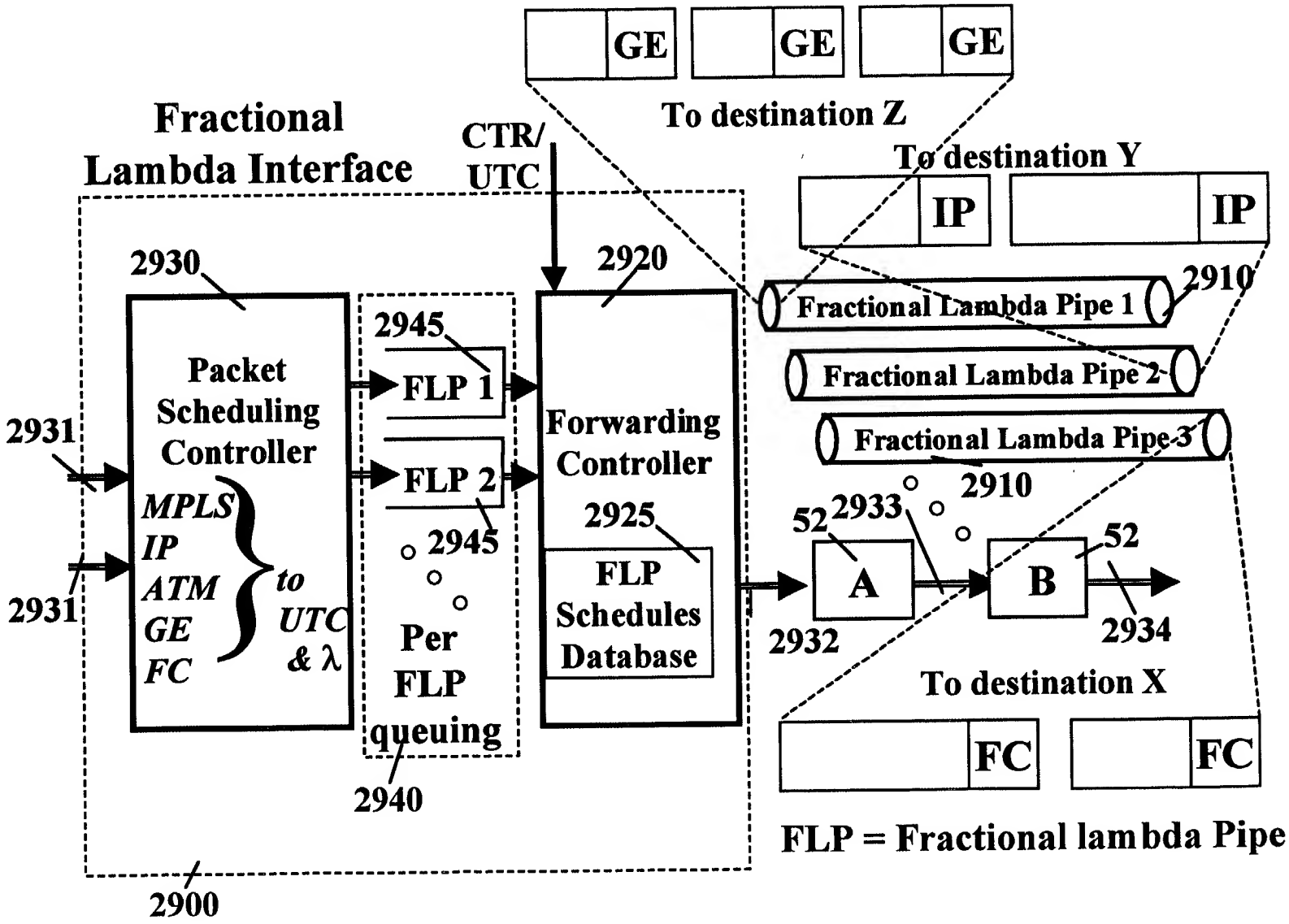

GE
GE
GE
To destination Z
Fractional Lambda Interface
CTR/ UTC
To destination Y
IP
IP
2930
2920
2910
Fractional Lambda Pipe 1
Fractional Lambda Pipe 2
Fractional Lambda Pipe 3
2945
FLP 1
FLP 2
2945
Packet Scheduling Controller
MPLS
IP
ATM
GE
FC
to UTC & λ
2931
2931
Forwarding Controller
2925
FLP Schedules Database
Per FLP queuing
2940
2910
52
2933
52
A
B
2932
2934
To destination X
FC
FC
FLP = Fractional lambda Pipe
2900

FIG. 32

Channel Capacity		TF Duration	TF Size		STS-1s	TFs/s
51.84	STS- 1	250	1620	1512	2	4000
		500	3240	3024	4	2000
		1000	6480	6048	8	1000
155.52	STS- 3	125	2430	2268	3	8000
		250	4860	4536	6	4000
		500	9720	9072	12	2000
622.08	STS- 12	62.5	4860	4536	6	16000
		125	9720	9072	12	8000
		250	19440	18144	24	4000
2488.32	STS- 48	62.5	19440	18144	24	16000
		31.25	9720	9072	12	32000
		15.625	4860	4536	6	64000
9953.28	STS- 192	7.8125	9720	9072	12	128000
		15.625	19440	18144	24	64000
1000	GE	125	15625	15625	19.3	8000
		100	12500	12500	15.4	10000
		80	10000	10000	12.3	12500
10000	10GE	15.625	19531.25	19531.3	24.1	64000
		12.5	15625	15625	19.3	80000
		10	12500	12500	15.4	100000

FIG. 33

Ch Capacity		TF Dur.	TF Size	GE TFs	TFs/s
1000	GE	80	10000	1.0	12500
51.84	STS- 1	250	1512	0.15	4000
		500	3024	0.30	2000
		1000	6048	0.60	1000
155.5	STS- 3	125	2268	0.23	8000
		250	4536	0.45	4000
		500	9072	0.91	2000
622.1	STS- 12	62.5	4536	0.45	16000
		125	9072	0.91	8000
		250	18144	1.81	4000
2488	STS- 48	62.5	18144	1.81	16000
		31.25	9072	0.91	32000
		15.625	4536	0.45	64000
9953	STS- 192	7.8125	9072	0.91	128000
		15.625	18144	1.81	64000
10000	10GE	8	10000	1.00	125000
		16	20000	2.00	62500

FIG. 34

Ch Capacity		TF Dur.	TF Size	GE TFs	TFs/s
1000	GE	62.5	7812.5	1.0	16000
51.84	STS- 1	250	1512	0.19	4000
		500	3024	0.39	2000
		1000	6048	0.77	1000
155.52	STS- 3	125	2268	0.29	8000
		250	4536	0.58	4000
		500	9072	1.16	2000
622.08	STS- 12	62.5	4536	0.58	16000
		125	9072	1.16	8000
		250	18144	2.32	4000
2488.32	STS- 48	62.5	18144	2.32	16000
		31.25	9072	1.16	32000
		15.625	4536	0.58	64000
9953.28	STS- 192	7.8125	9072	1.16	128000
		15.625	18144	2.32	64000
10000	10GE	12.5	15625	2.00	80000
		25	31250	4.00	40000

FIG. 35

***TF Alignment of* UTR(j) *to* UTC -** **with three input queues - principle of operation:**

The same queue is not used simultaneously for:

1. Receiving data packets from the serial link, and

2. Forwarding data packets to the switch

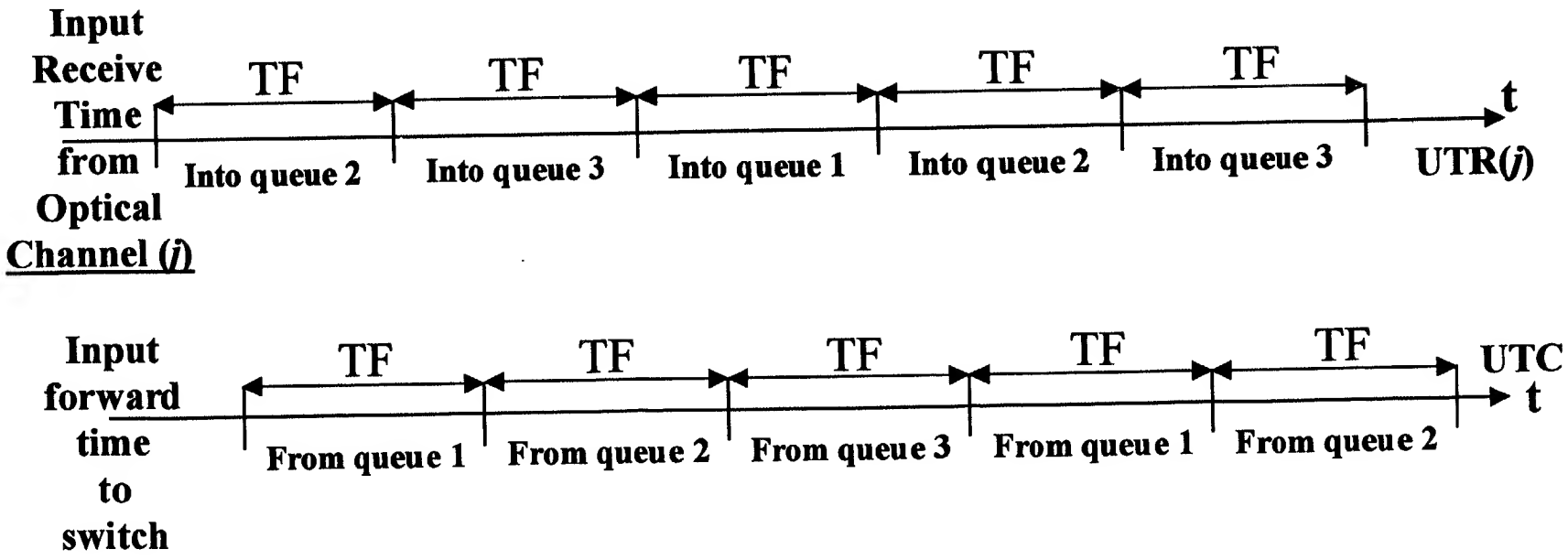


FIG. 36

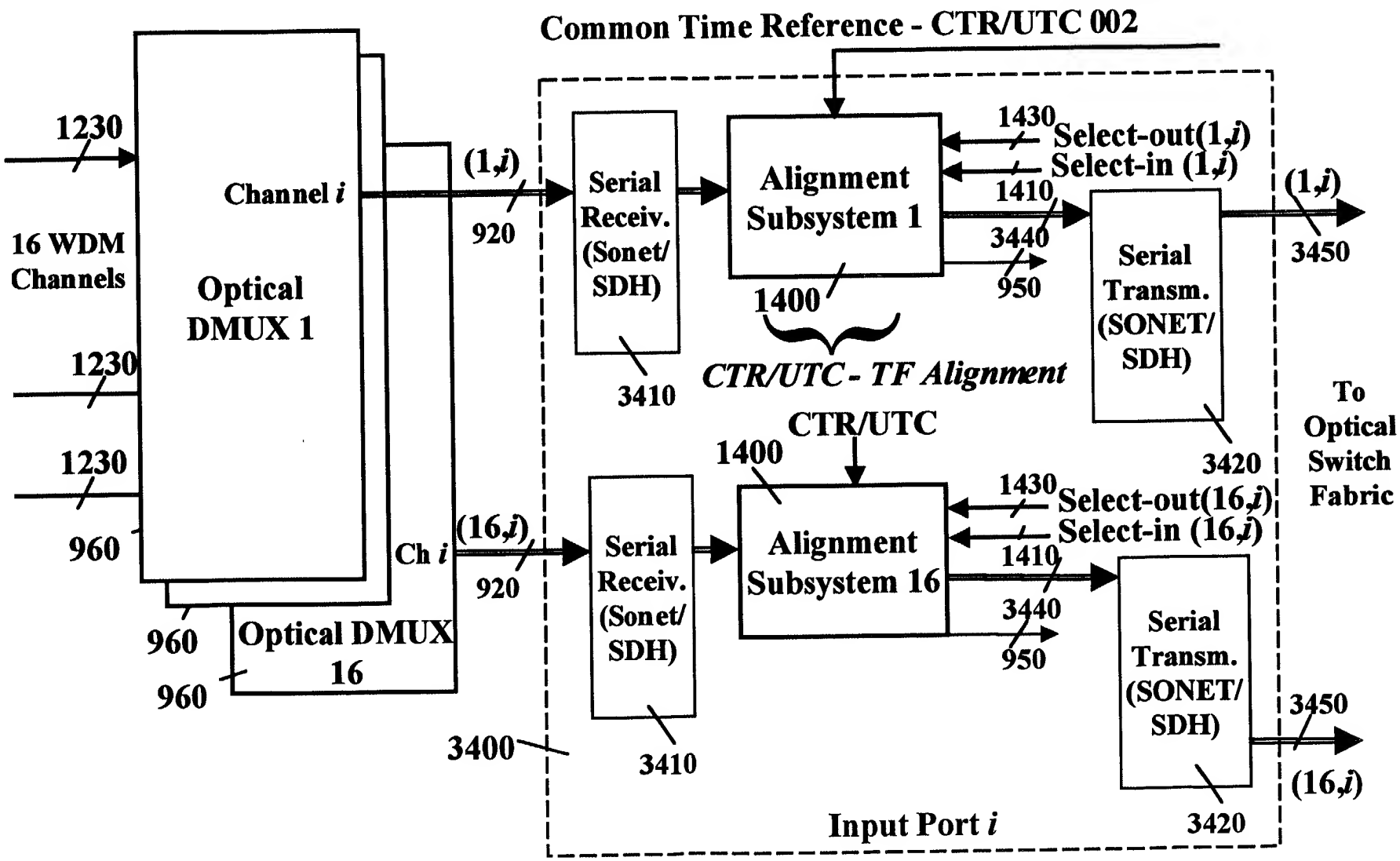


FIG. 37

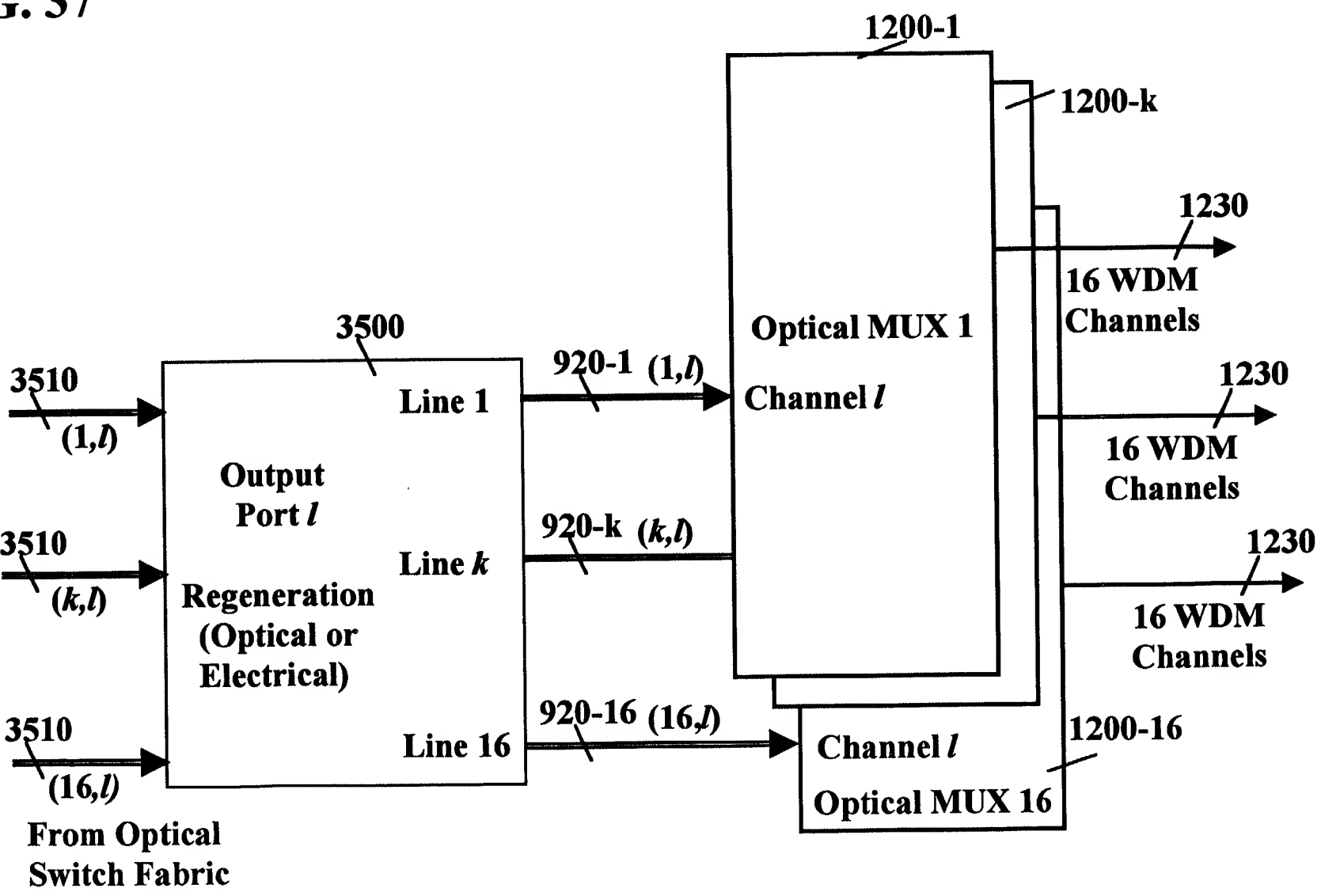

1200-1
1200-k
1230
16 WDM Channels
Optical MUX 1
Channel l
3500
3510
(1,l)
Line 1
920-1 (1,l)
1230
16 WDM Channels
Output Port l
3510
(k,l)
Line k
920-k (k,l)
Regeneration (Optical or Electrical)
1230
16 WDM Channels
3510
(16,l)
Line 16
920-16 (16,l)
Channel l
1200-16
Optical MUX 16
From Optical Switch Fabric

FIG. 38

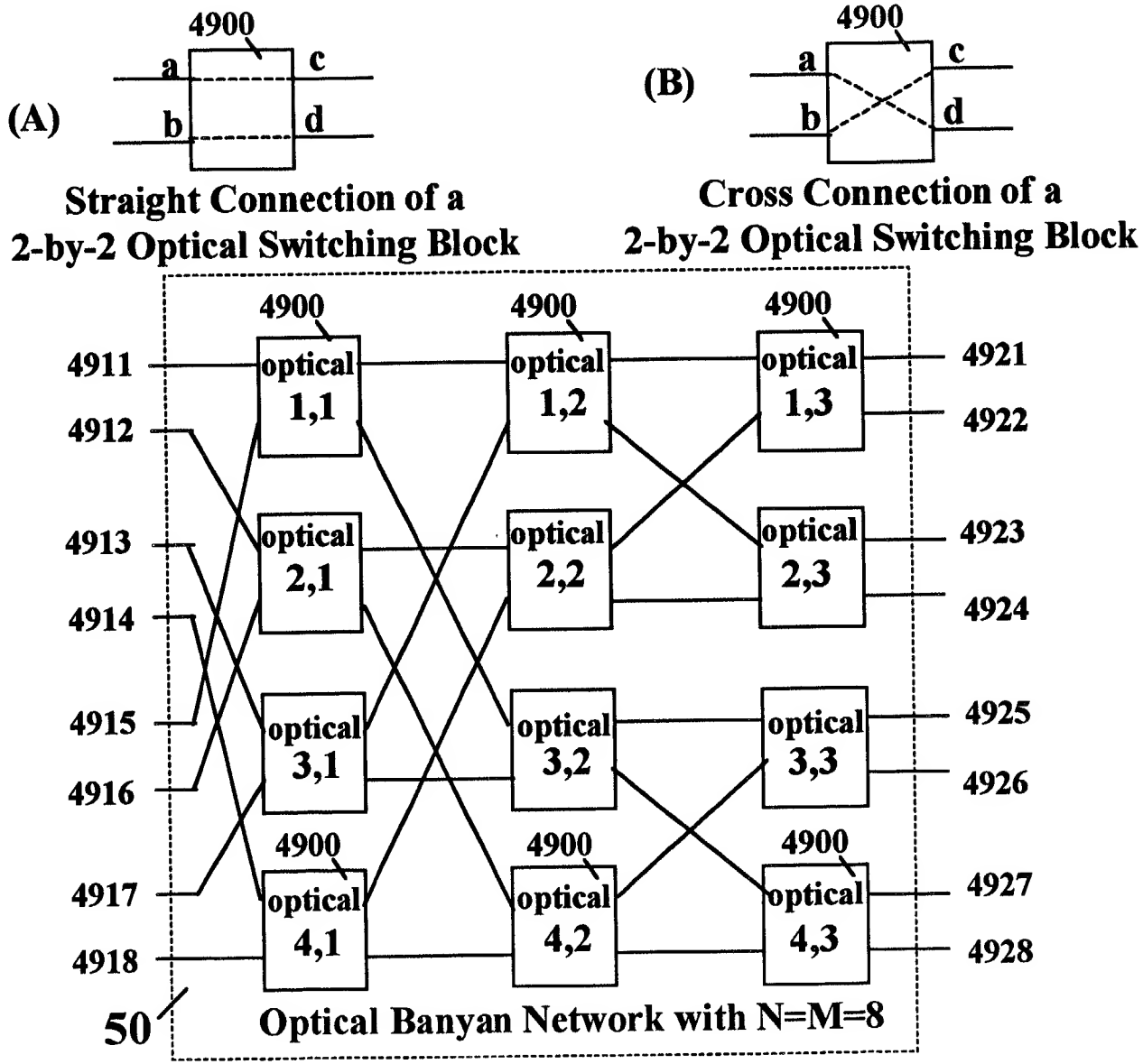


FIG. 39

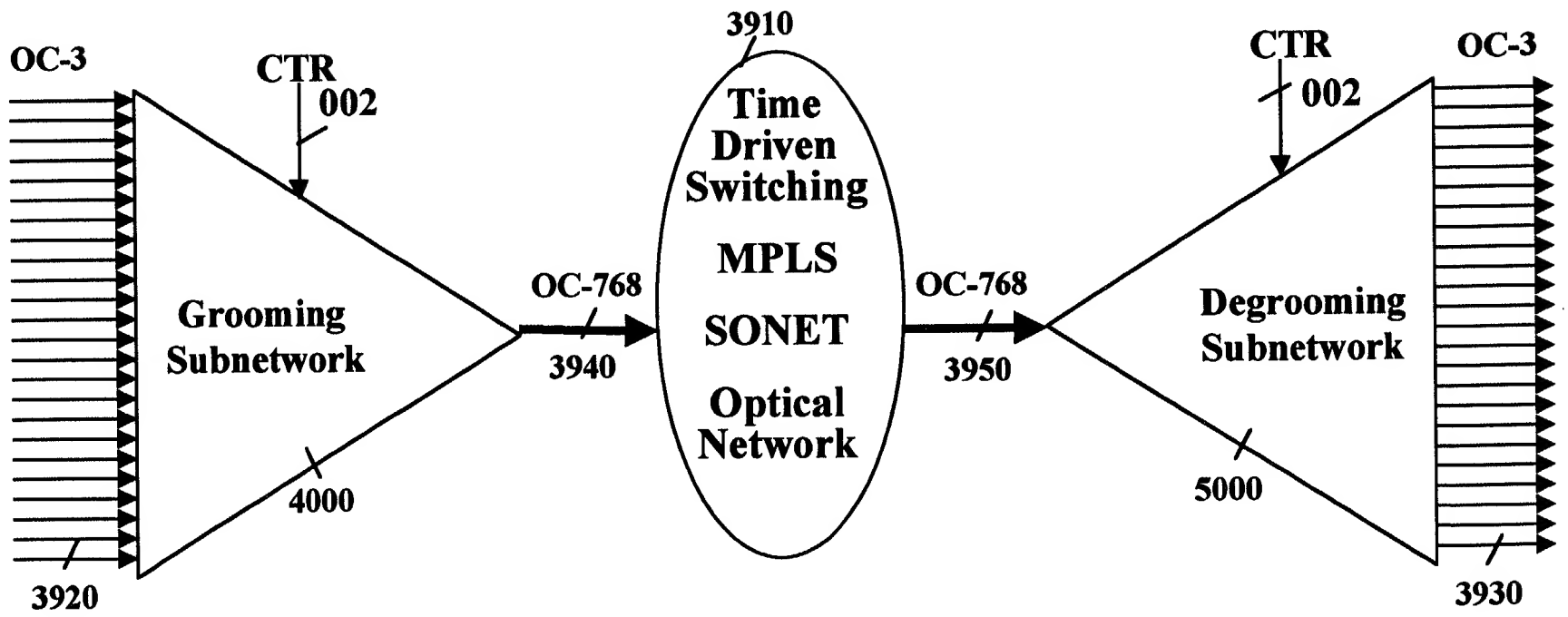


FIG. 40

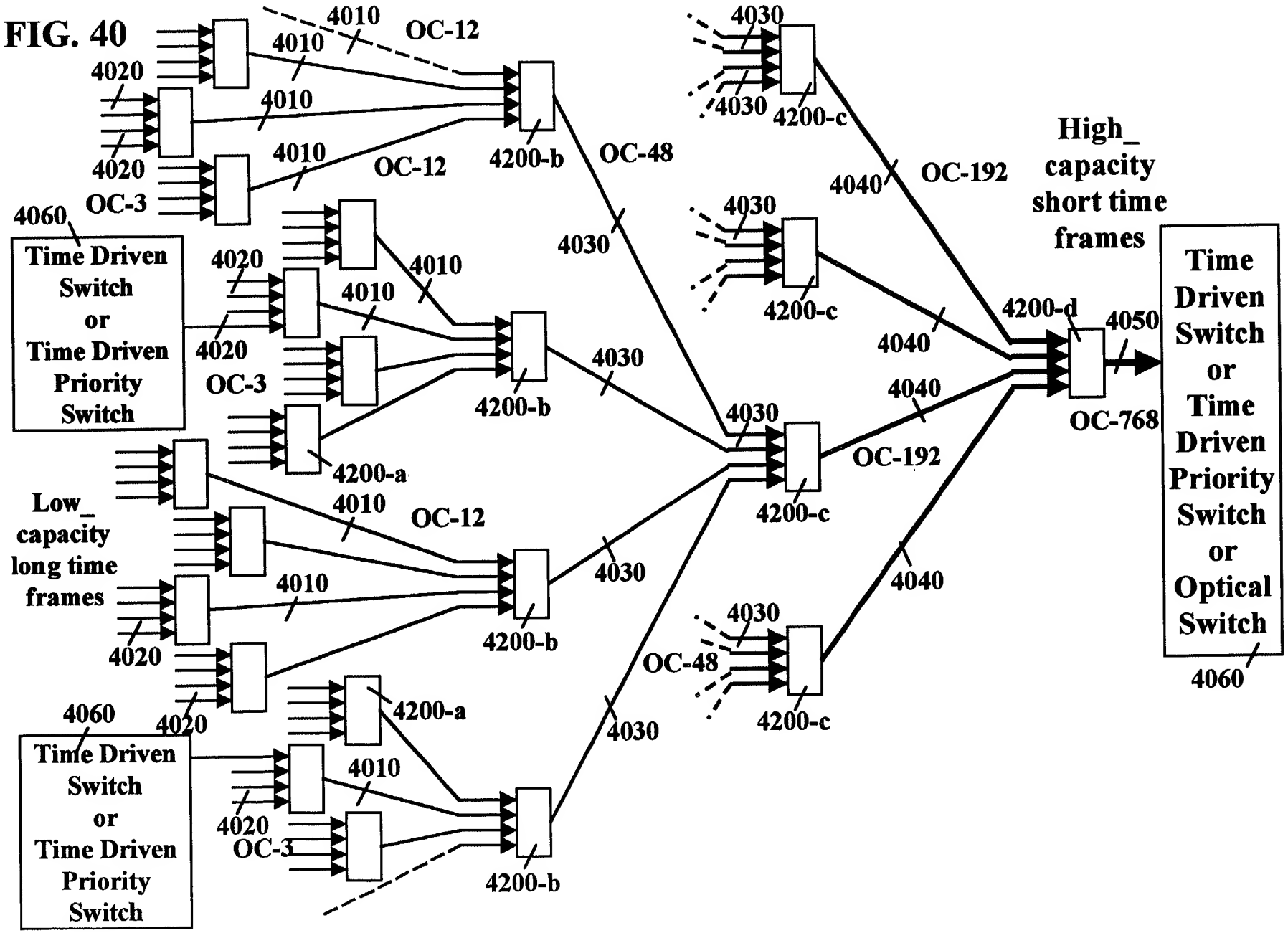

4010
OC-12
4020
4010
4020
OC-3
4060
Time Driven Switch or Time Driven Priority Switch
4200-b
OC-48
4030
4200-a
Low_ capacity long time frames
4200-c
4040
OC-192
High_ capacity short time frames
4200-d
4050
OC-768
Time Driven Switch or Time Driven Priority Switch or Optical Switch

FIG. 41

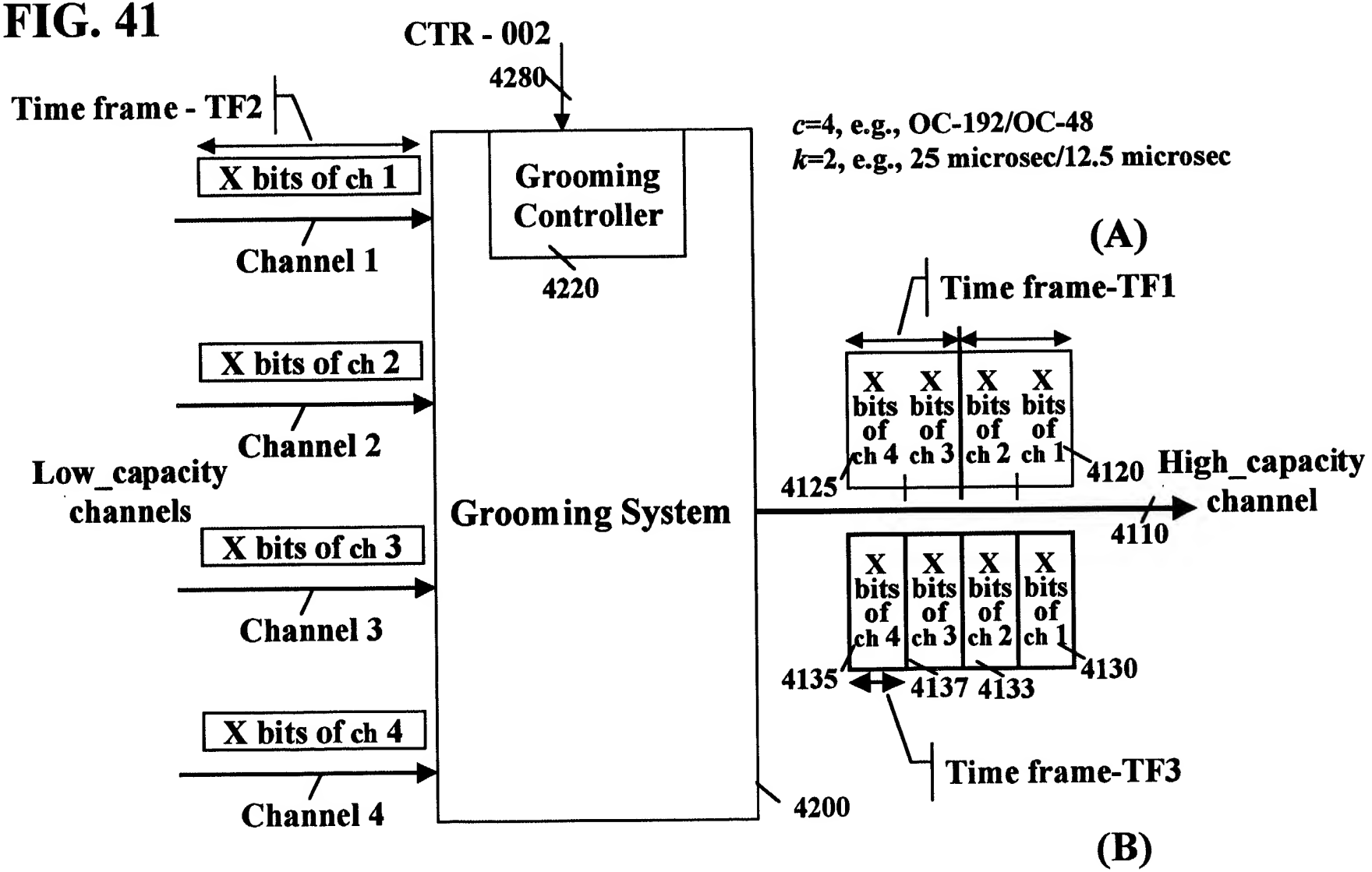


FIG. 42

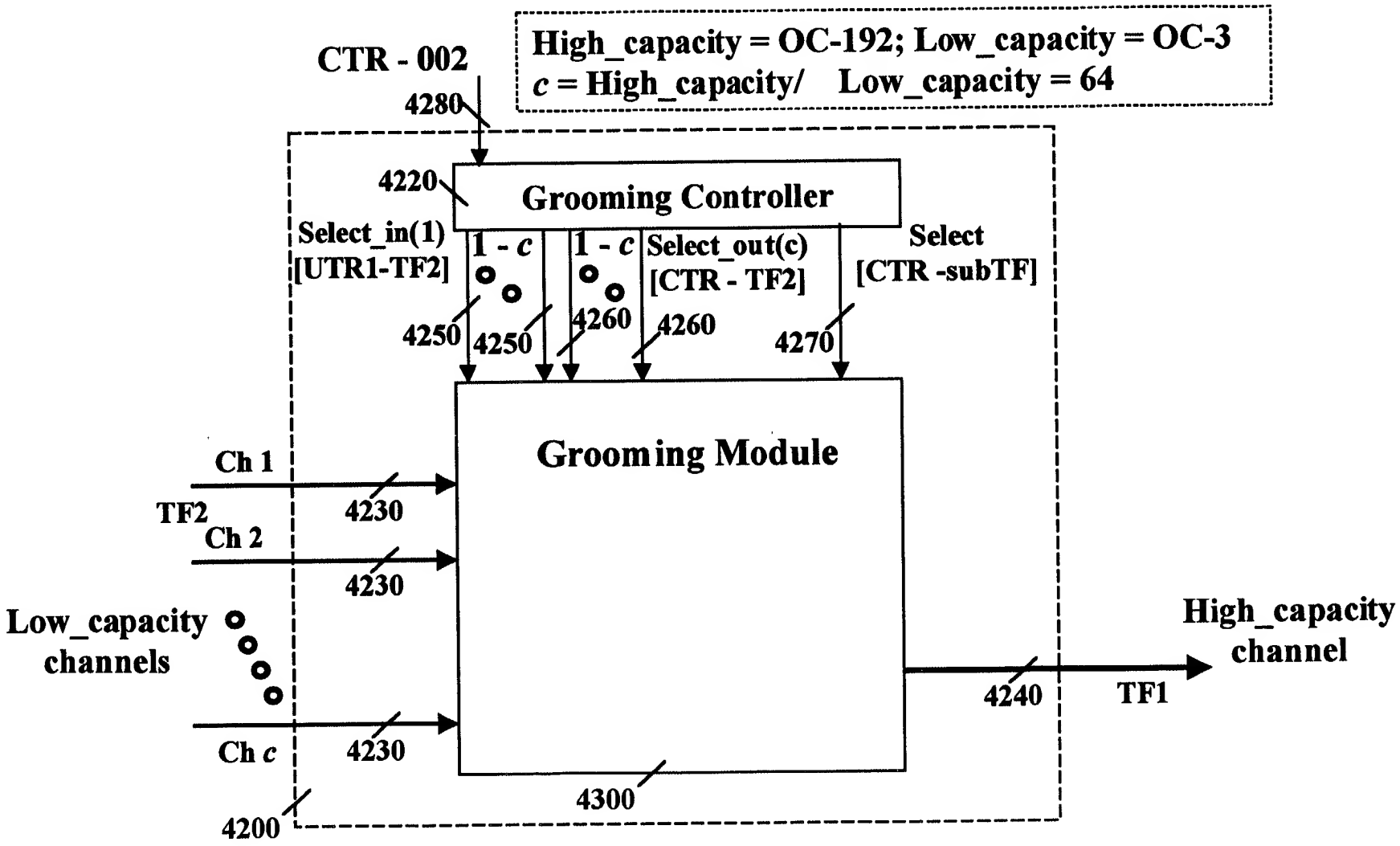


FIG. 43

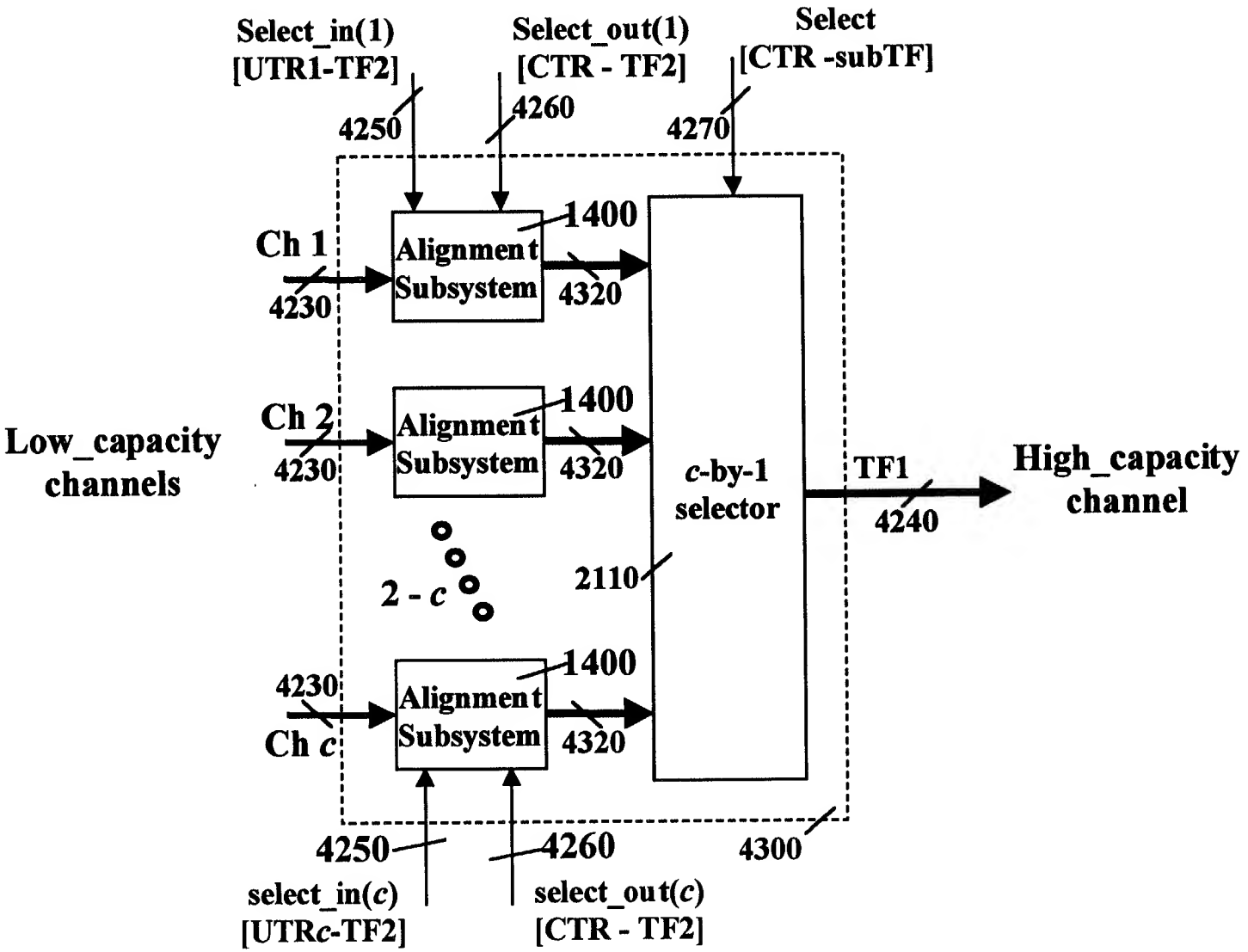


FIG. 44

- $CC1\_length \cdot TF1 = CC2\_length \cdot TF2 = CC3\_length \cdot TF2$
- $TF2 = (SC1\_length / SC2\_length) \cdot TF1 = k \cdot TF1$, where the common cycles of *TF1* and *TF2* are aligned with respect to UTC.

For $k = 2$ and $c = 4$ (e.g., High_capacity=OC-192, Low_capacity=OC-48):

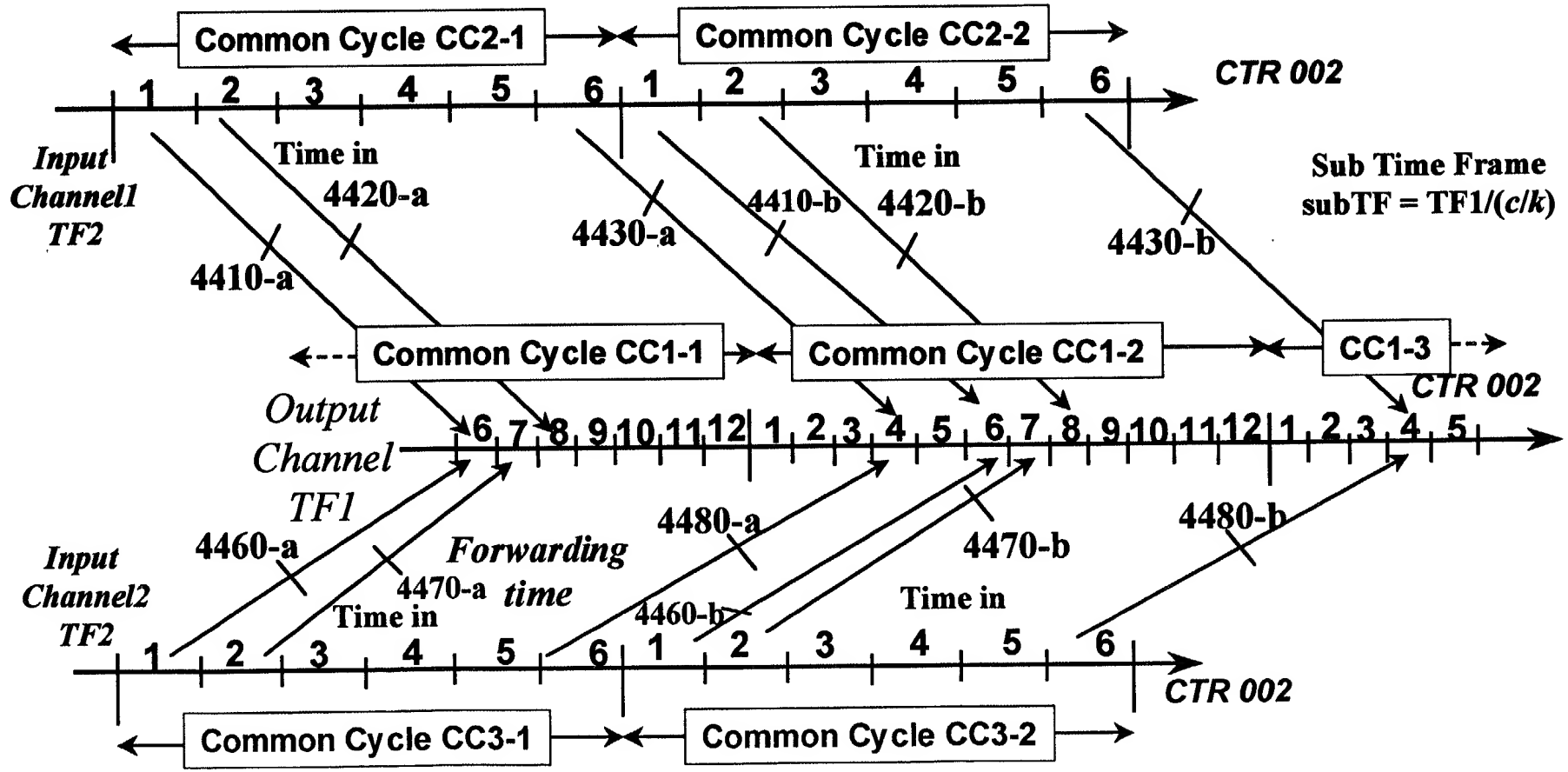


FIG. 45

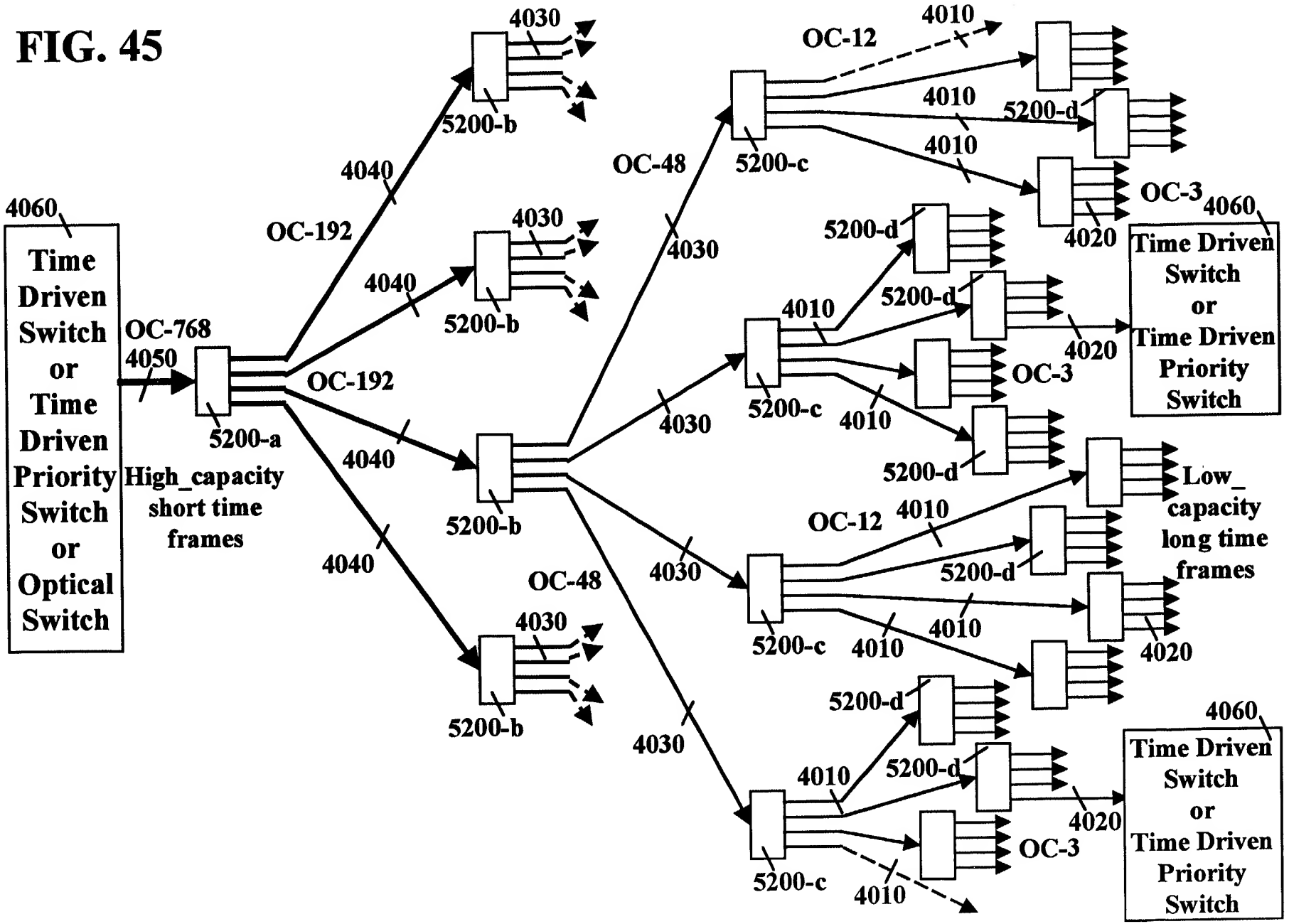
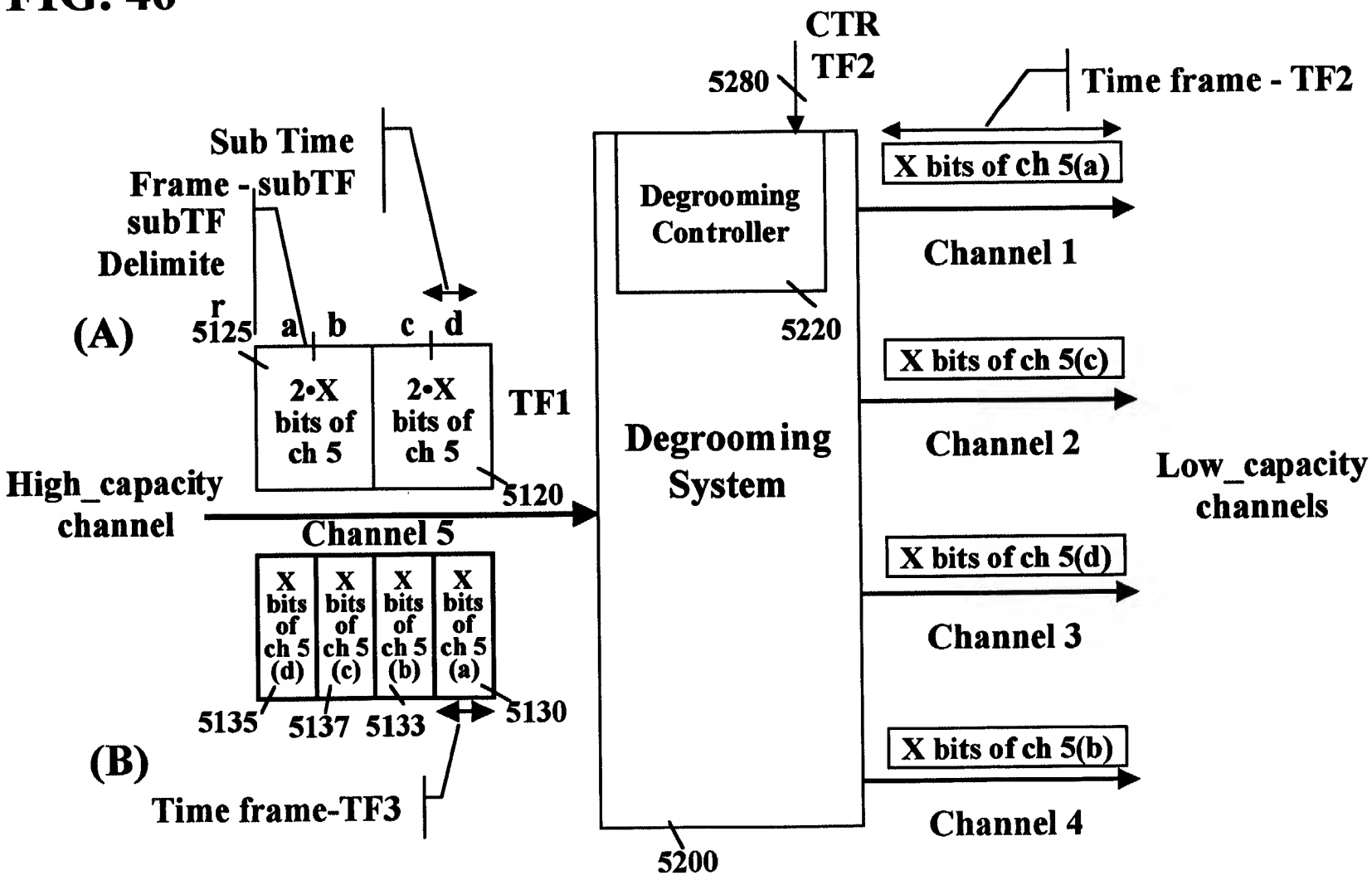

4060
Time Driven Switch or Time Driven Priority Switch or Optical Switch
OC-768
4050
5200-a
High_capacity short time frames
OC-192
4040
OC-192
4040
4040
4030
5200-b
4030
5200-b
4030
5200-b
OC-48
4030
4030
4030
OC-48
5200-c
OC-12
4010
4010
4010
5200-d
OC-3
4020
4060
Time Driven Switch or Time Driven Priority Switch
5200-c
4010
5200-d
5200-d
OC-3
4020
4010
5200-d
5200-c
OC-12
4010
5200-d
Low_ capacity long time frames
4020
4010
4010
5200-c
5200-d
4010
5200-d
OC-3
4020
4060
Time Driven Switch or Time Driven Priority Switch
4010
5200-c

FIG. 46



c=4, e.g., OC-192/OC-48
k=2, e.g., 25 microsec/12.5 microsec

FIG. 47

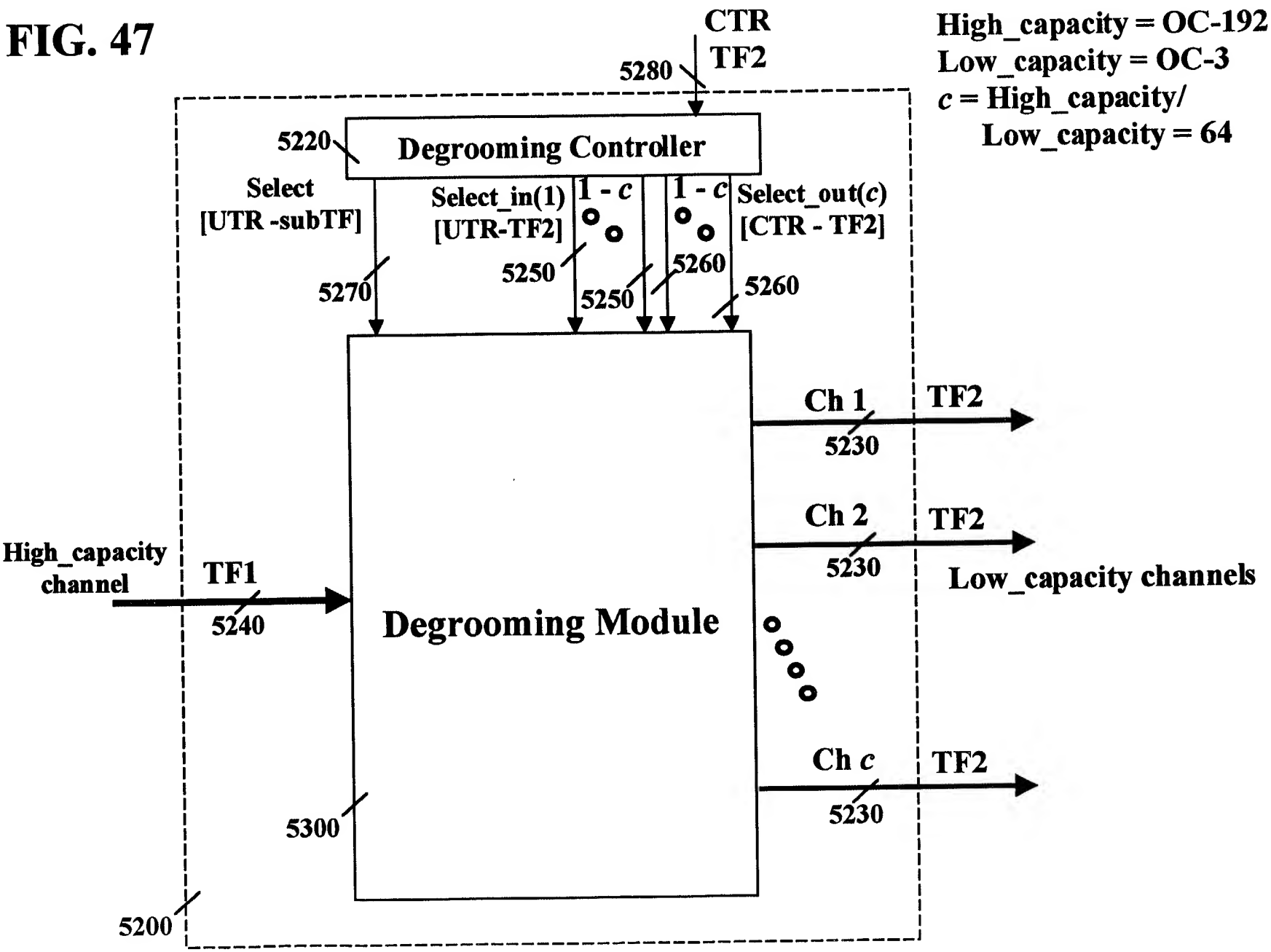


FIG. 48

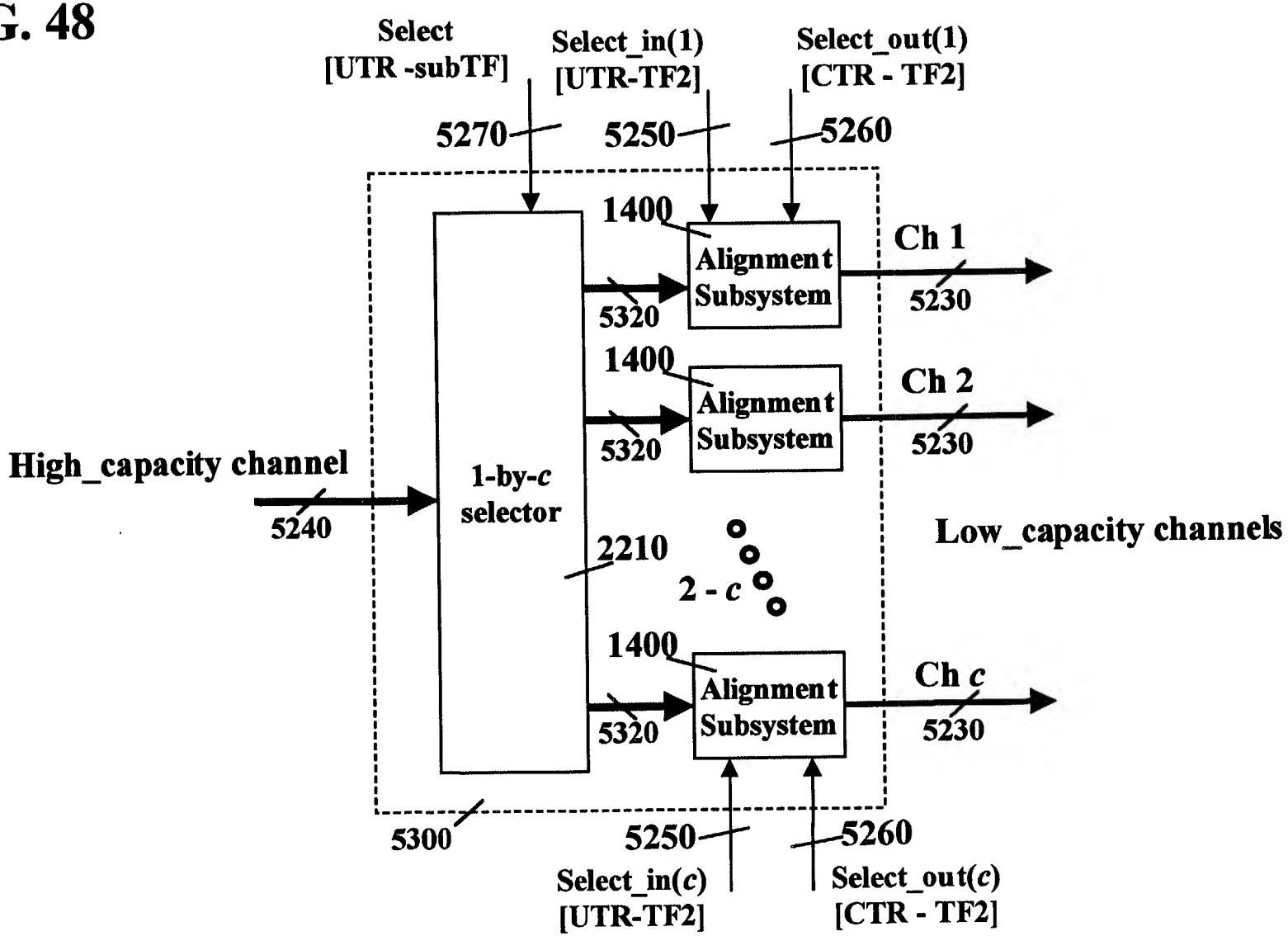


FIG. 49

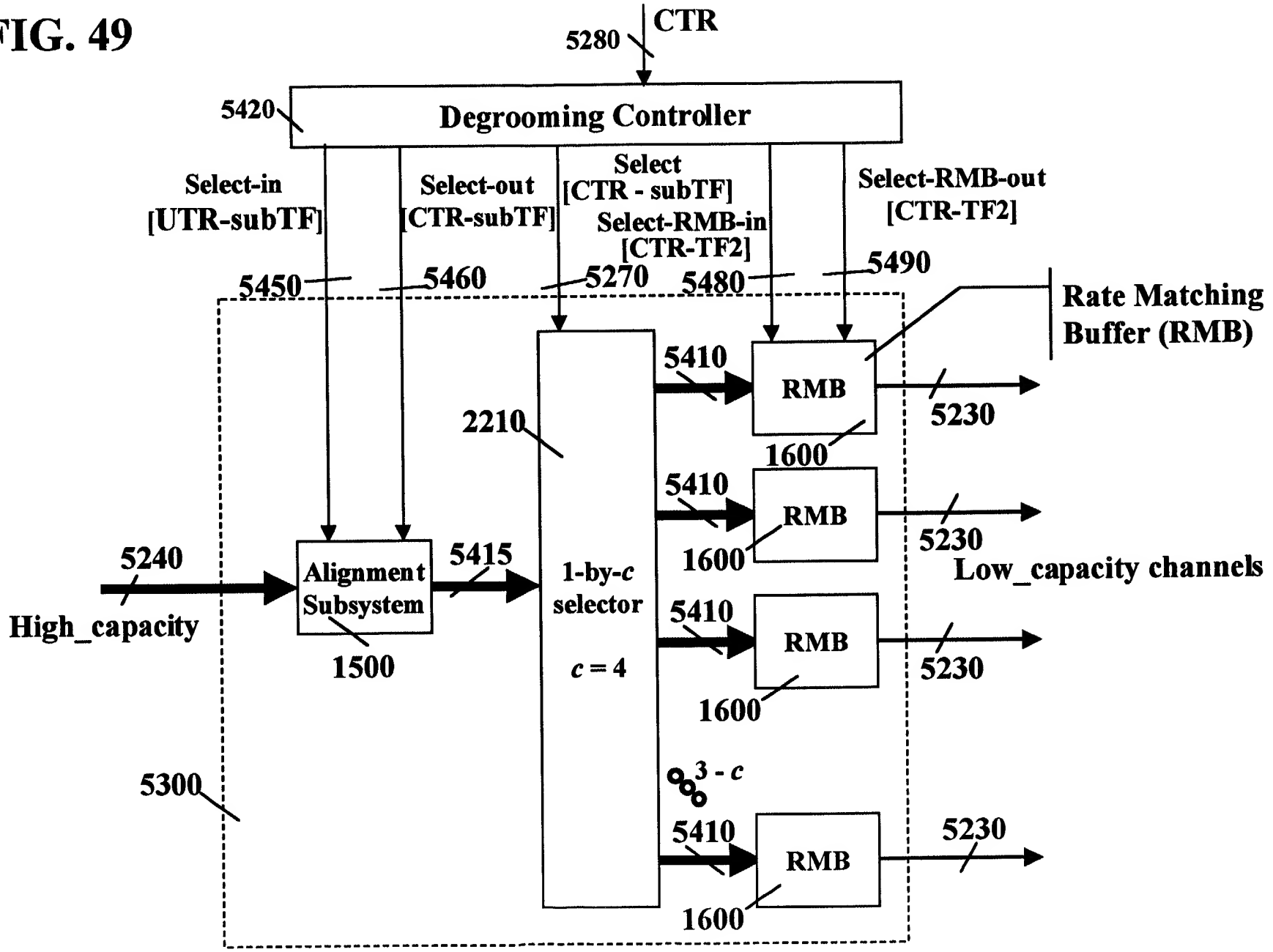


FIG. 50

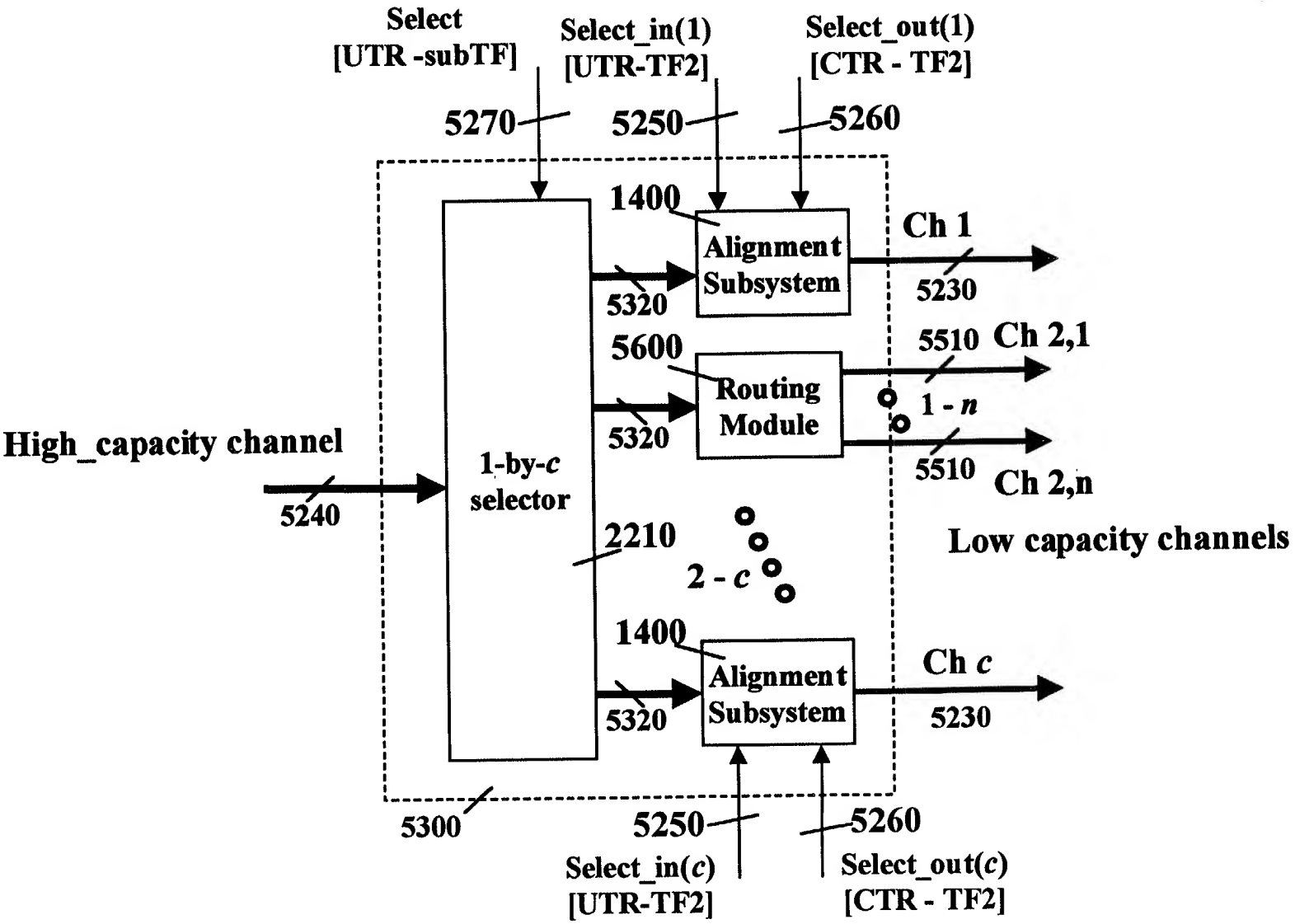


FIG. 51

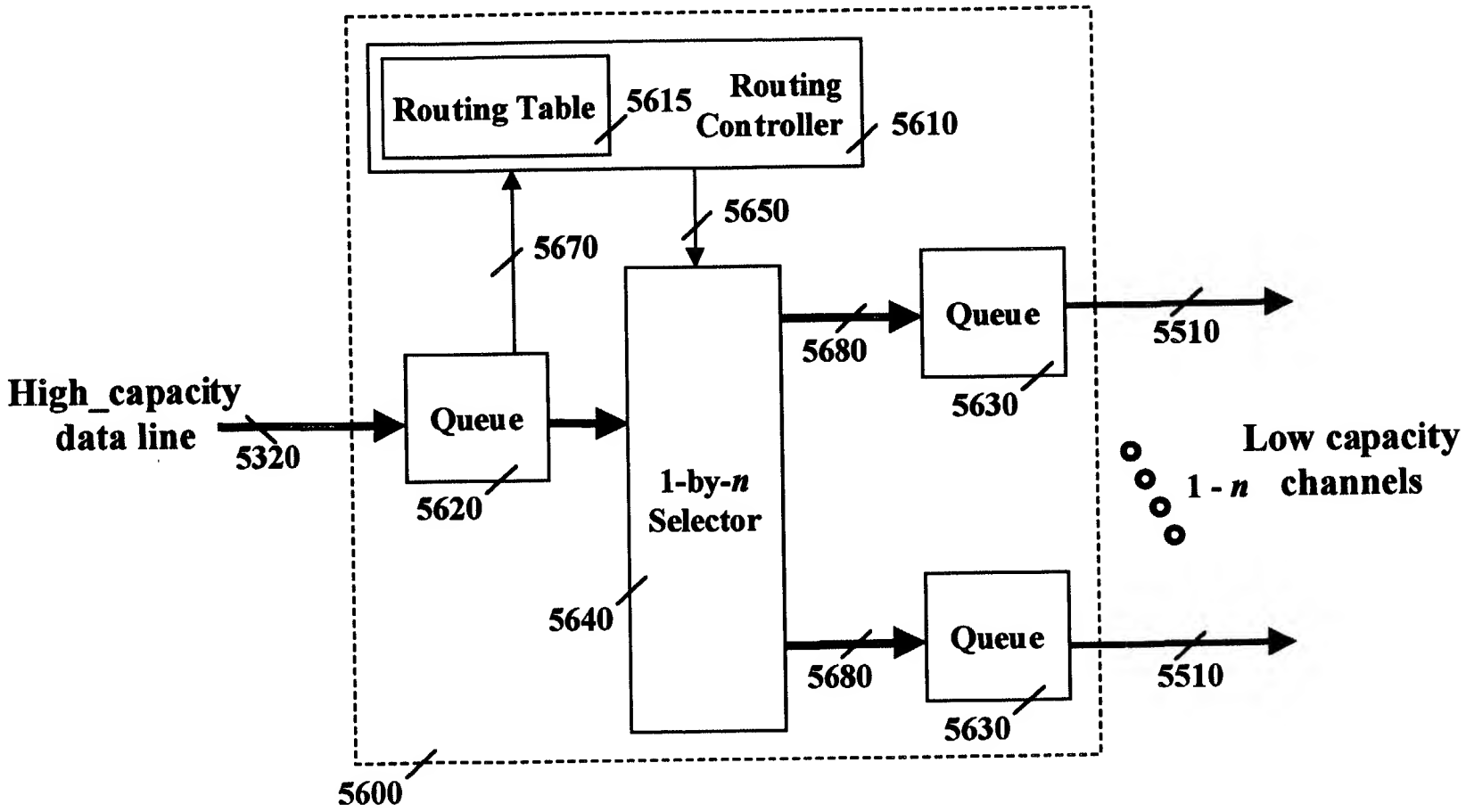

Routing Table
5615
Routing Controller
5610
5650
5670
High_capacity data line
5320
Queue
5620
1-by-n Selector
5640
Queue
5680
5630
5510
Queue
5680
5630
5510
Low capacity
1 - n channels
5600

FIG. 52

- $CC1\_length \cdot TF1 = CC2\_length \cdot TF2 = CC3\_length \cdot TF2$
- $TF2 = (SC1\_length / SC2\_length) \cdot TF1 = k \cdot TF1$, where the common cycles of *TF1* and *TF2* are aligned with respect to UTC.

For $k = 2$ and $c = 4$ (e.g., High_capacity=OC-192, Low_capacity=OC-48):

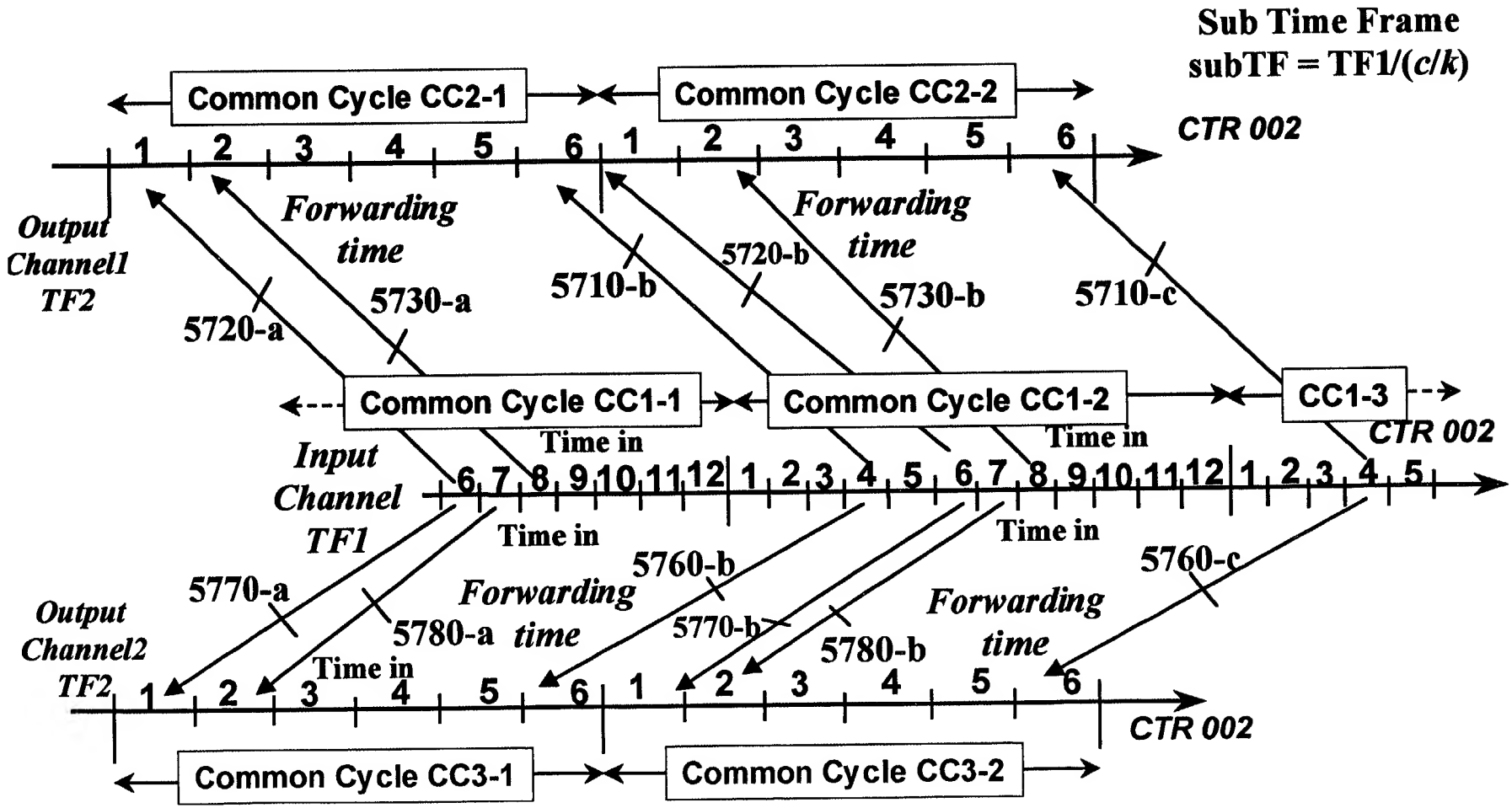


FIG. 53

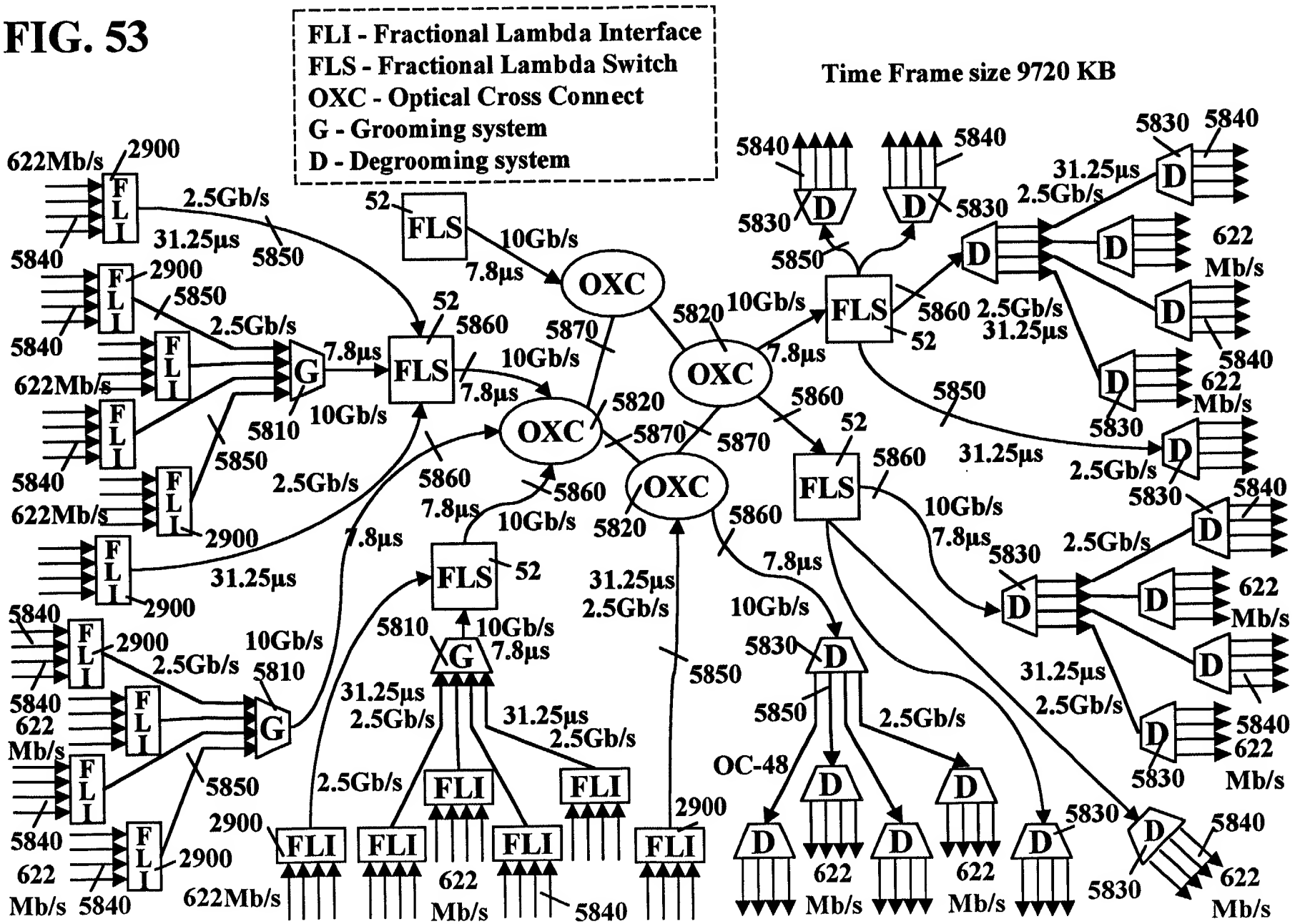

FLI - Fractional Lambda Interface
FLS - Fractional Lambda Switch
OXC - Optical Cross Connect
G - Grooming system
D - Degrooming system
Time Frame size 9720 KB
622Mb/s
2900
2.5Gb/s
31.25µs
5850
5840
52
FLS
10Gb/s
7.8µs
OXC
5820
5870
5860
5810
G
D
FLI
622 Mb/s
OC-48
5830

FIG. 54

FLI - Fractional Lambda Interface
FLS - Fractional Lambda Switch
OXC - Optical Cross Connect
G - Grooming system
D - Degrooming system

12 STS-1s per time frame

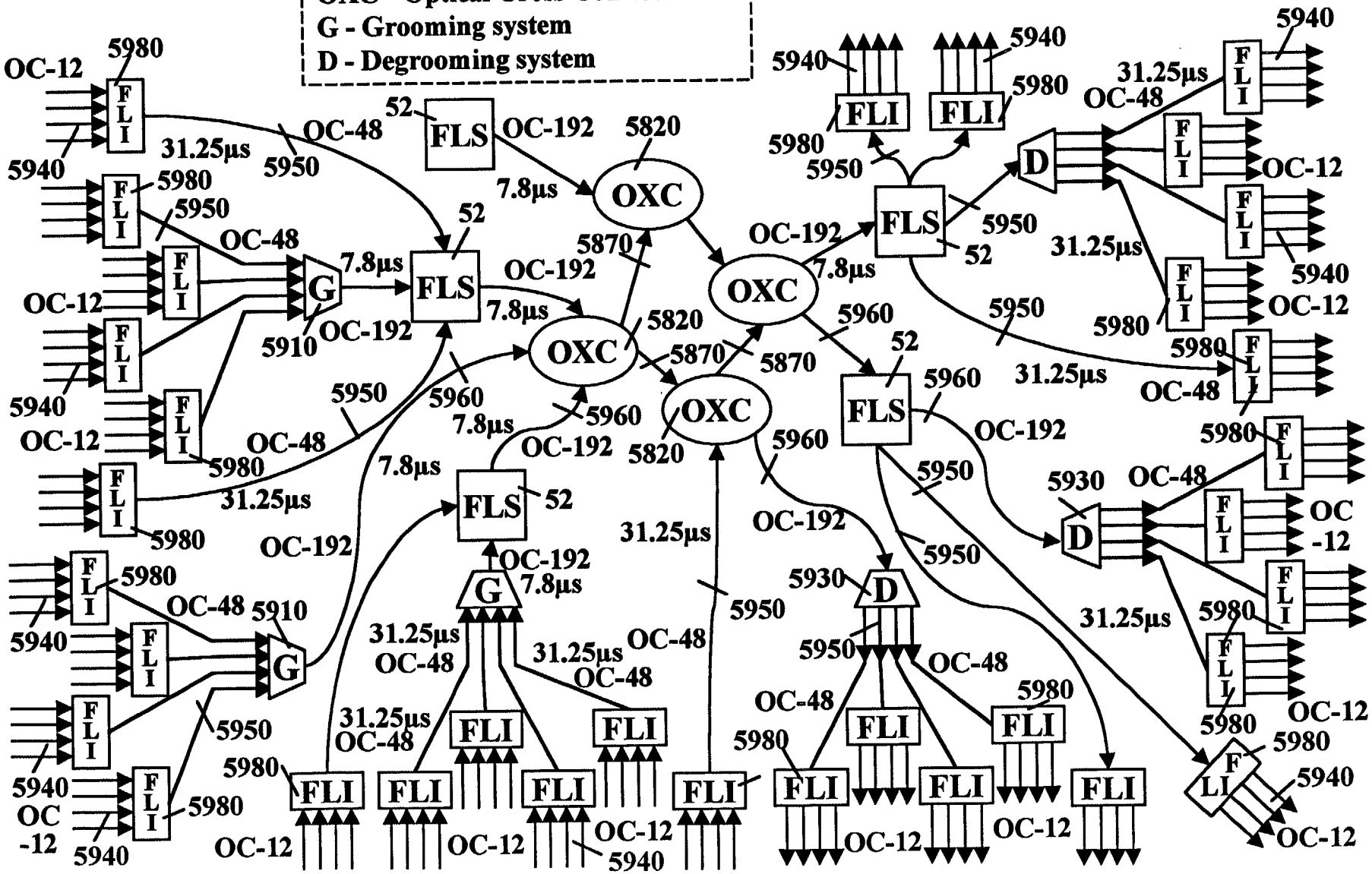


FIG. 55

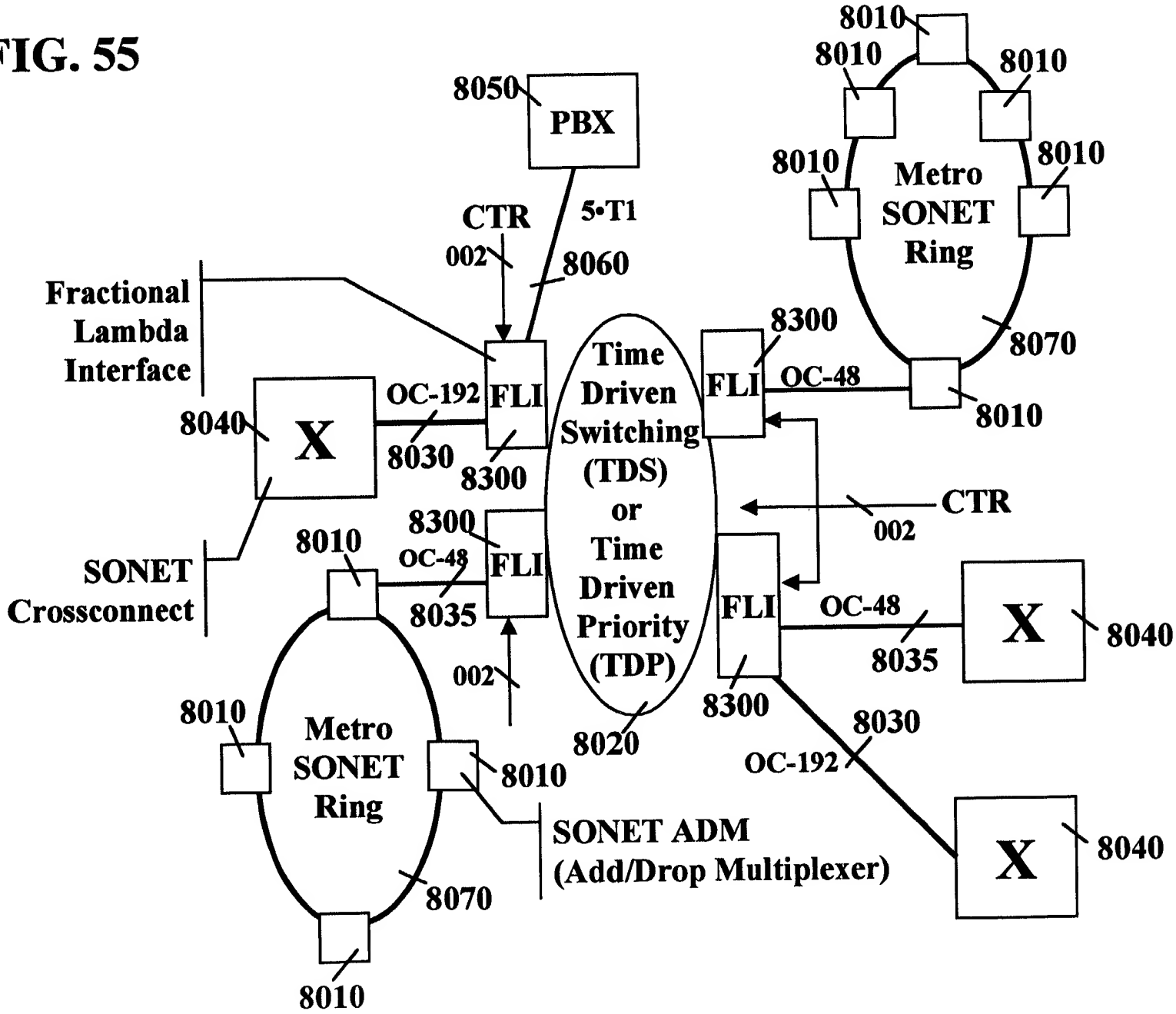

8010
8010
8010
8010
8010
Metro
SONET
Ring
8070
8050
PBX
CTR
002
5•T1
8060
Fractional
Lambda
Interface
8300
FLI
OC-48
8010
8040
X
OC-192
FLI
8030
8300
Time
Driven
Switching
(TDS)
or
Time
Driven
Priority
(TDP)
8020
CTR
002
8300
FLI
8010
OC-48
8035
SONET
Crossconnect
FLI
OC-48
X
8040
8035
002
8300
8030
OC-192
8010
Metro
SONET
Ring
8010
SONET ADM
(Add/Drop Multiplexer)
X
8040
8070
8010

FIG. 56

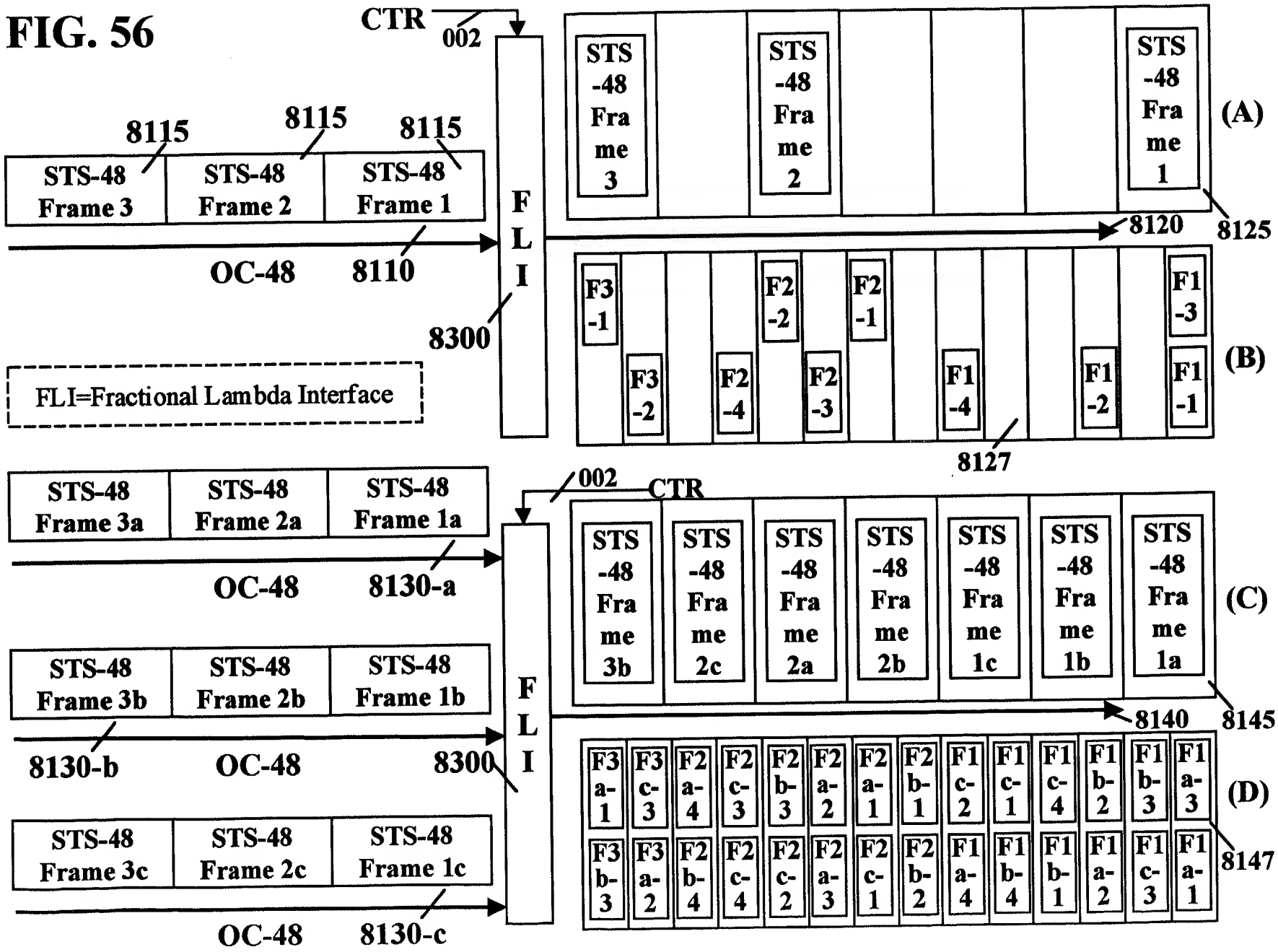

CTR
002
8115
8115
8115
STS-48 Frame 3
STS-48 Frame 2
STS-48 Frame 1
OC-48
8110
8300
FLI
FLI=Fractional Lambda Interface
STS -48 Fra me 3
STS -48 Fra me 2
STS -48 Fra me 1
(A)
8120
8125
F3 -1
F3 -2
F2 -4
F2 -2
F2 -3
F2 -1
F1 -4
F1 -2
F1 -3
F1 -1
(B)
8127
STS-48 Frame 3a
STS-48 Frame 2a
STS-48 Frame 1a
OC-48
8130-a
002
CTR
STS -48 Fra me 3b
STS -48 Fra me 2c
STS -48 Fra me 2a
STS -48 Fra me 2b
STS -48 Fra me 1c
STS -48 Fra me 1b
STS -48 Fra me 1a
(C)
8140
8145
STS-48 Frame 3b
STS-48 Frame 2b
STS-48 Frame 1b
8130-b
OC-48
8300
F3 a-1
F3 c-3
F2 a-4
F2 c-3
F2 b-3
F2 a-2
F2 a-1
F2 b-1
F1 c-2
F1 c-1
F1 c-4
F1 b-2
F1 b-3
F1 a-3
F3 b-3
F3 a-2
F2 b-4
F2 c-4
F2 c-2
F2 a-3
F2 c-1
F2 b-2
F1 a-4
F1 b-4
F1 b-1
F1 a-2
F1 c-3
F1 a-1
(D)
8147
STS-48 Frame 3c
STS-48 Frame 2c
STS-48 Frame 1c
OC-48
8130-c

FIG. 57

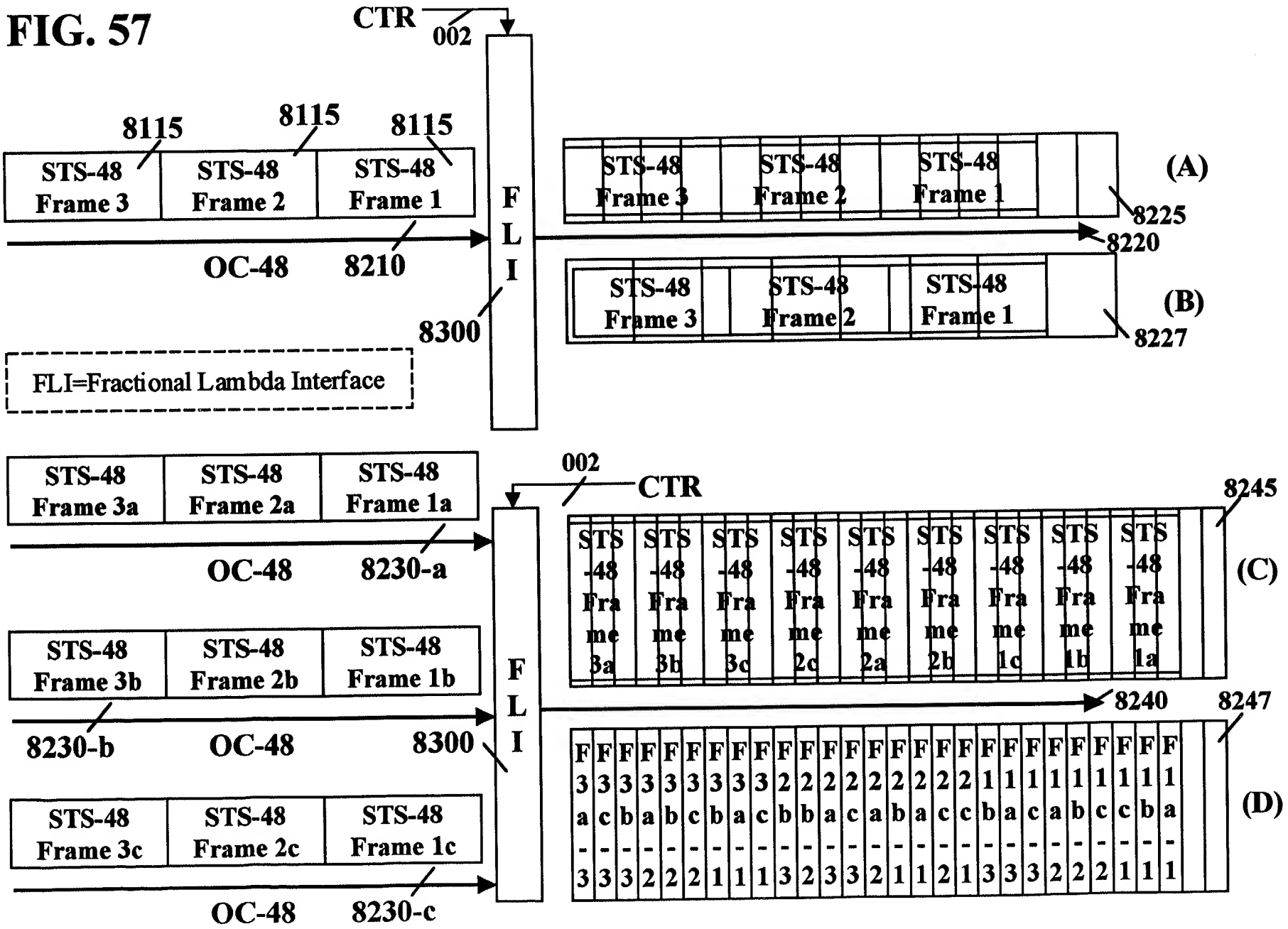

CTR
002
8115
8115
8115
STS-48 Frame 3
STS-48 Frame 2
STS-48 Frame 1
OC-48
8210
8300
FLI
FLI=Fractional Lambda Interface
STS-48 Frame 3
STS-48 Frame 2
STS-48 Frame 1
(A)
8225
8220
STS-48 Frame 3
STS-48 Frame 2
STS-48 Frame 1
(B)
8227
STS-48 Frame 3a
STS-48 Frame 2a
STS-48 Frame 1a
OC-48
8230-a
STS-48 Frame 3b
STS-48 Frame 2b
STS-48 Frame 1b
8230-b
OC-48
8300
STS-48 Frame 3c
STS-48 Frame 2c
STS-48 Frame 1c
OC-48
8230-c
002
CTR
8245
STS-48 Frame 3a
STS-48 Frame 3b
STS-48 Frame 3c
STS-48 Frame 2c
STS-48 Frame 2a
STS-48 Frame 2b
STS-48 Frame 1c
STS-48 Frame 1b
STS-48 Frame 1a
(C)
8240
8247
F3a-3
F3c-3
F3b-3
F3a-2
F3b-2
F3c-2
F3b-1
F3a-1
F3c-1
F2b-3
F2a-2
F2c-3
F2a-3
F2b-2
F2a-1
F2c-1
F2b-1
F1c-3
F1b-3
F1a-3
F1c-2
F1a-2
F1b-2
F1c-1
F1b-1
F1a-1
(D)

FIG. 58

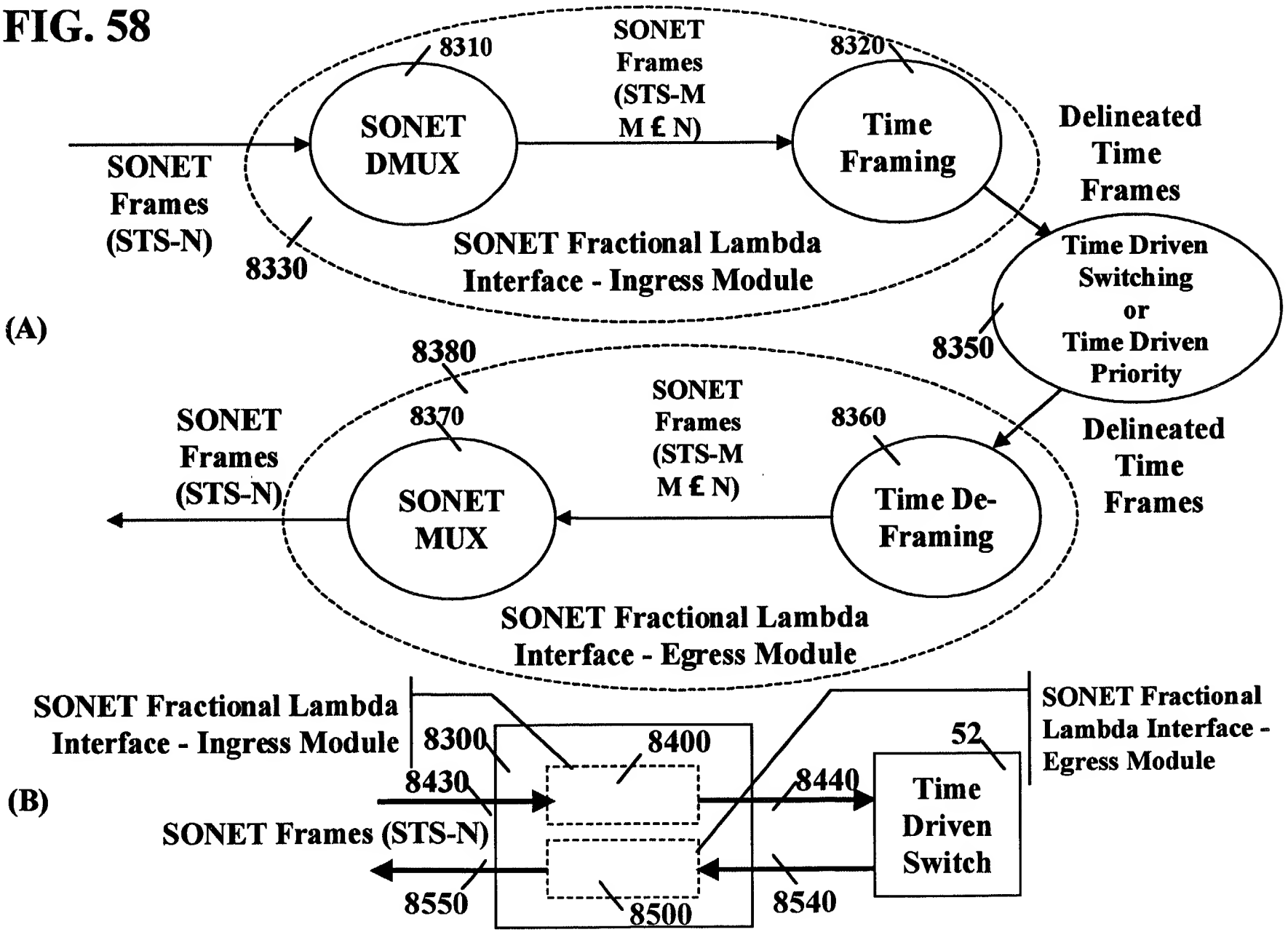


FIG. 59

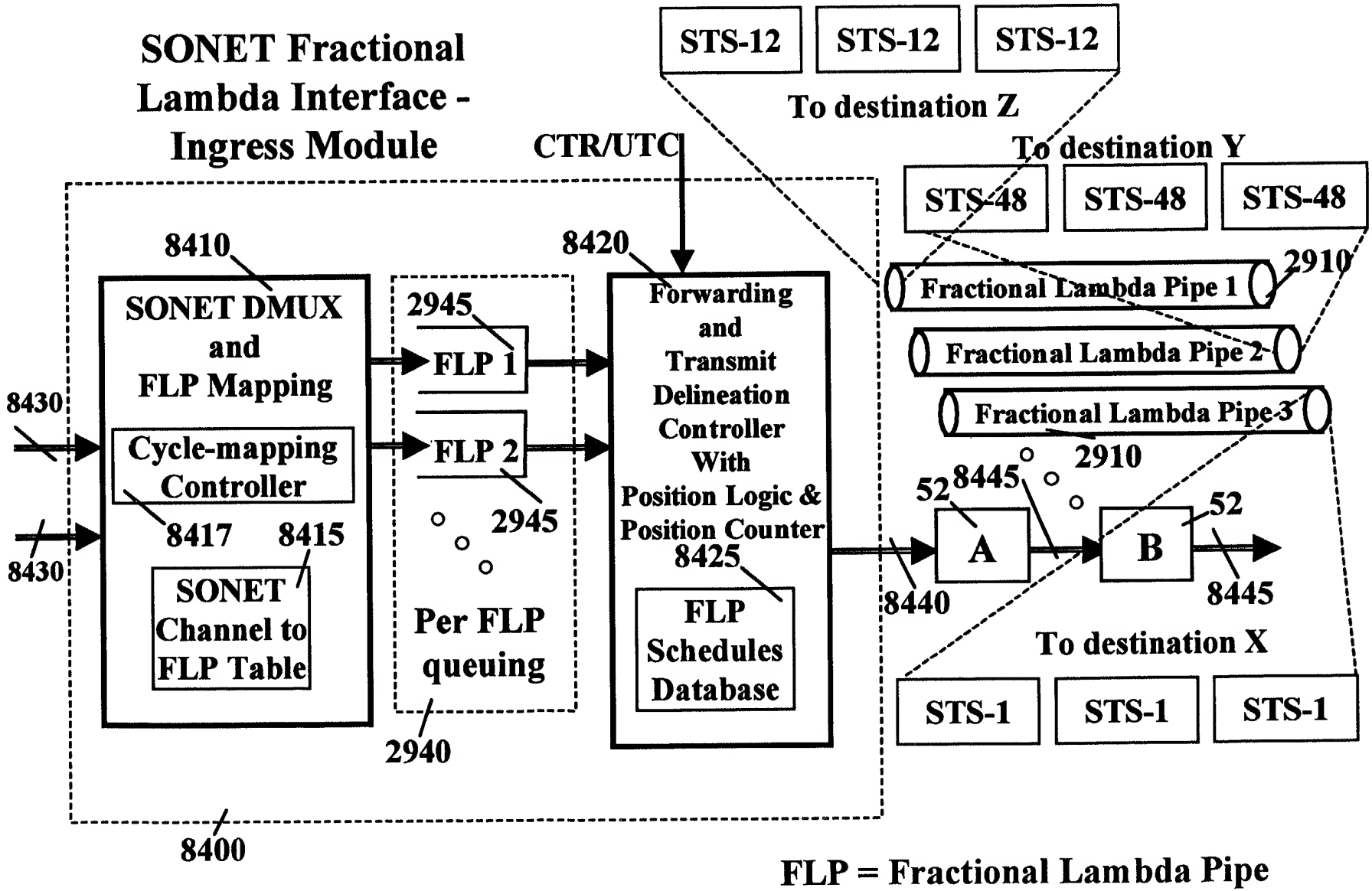
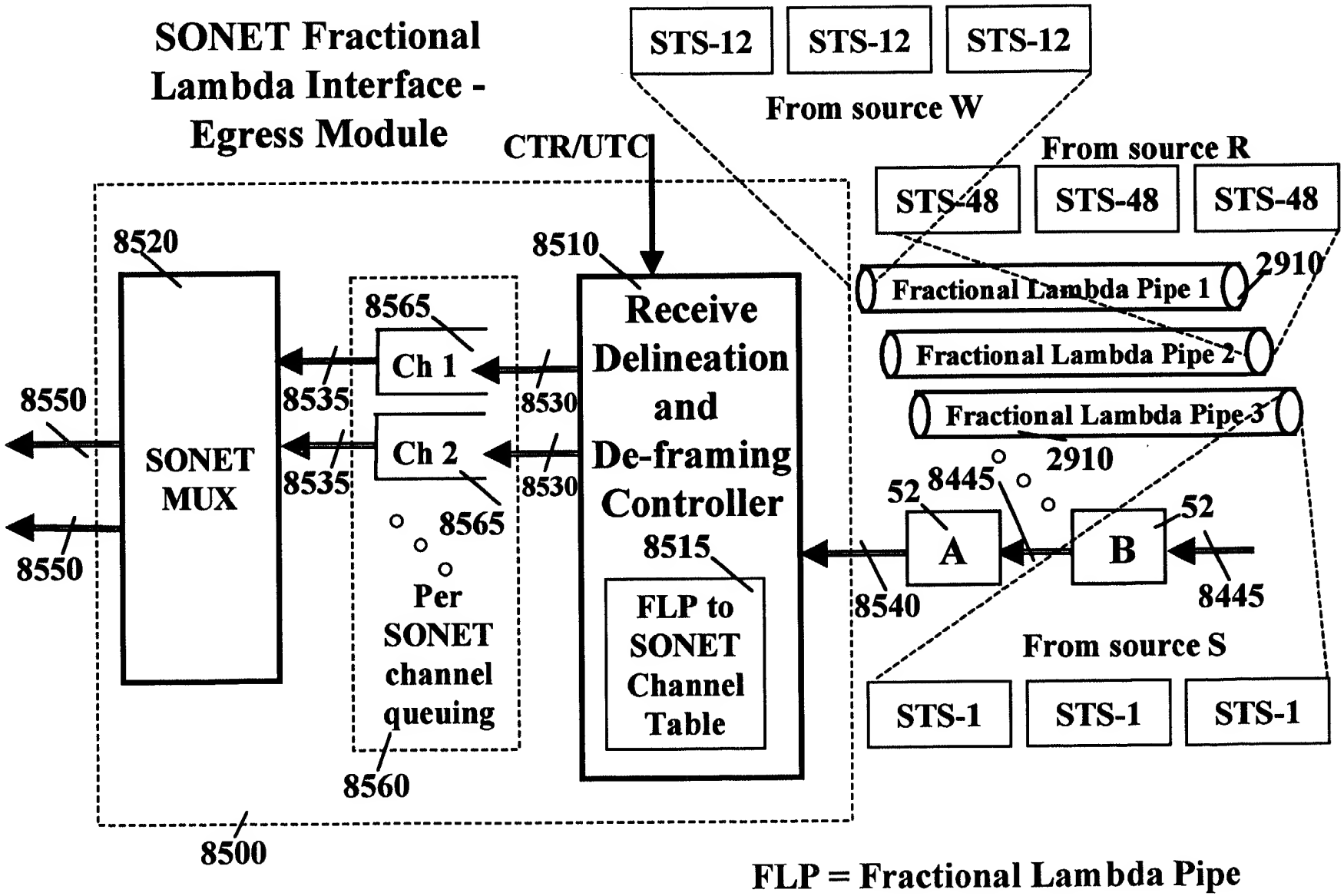


FIG. 60


SONET Fractional Lambda Interface - Egress Module
STS-12
STS-12
STS-12
From source W
From source R
STS-48
STS-48
STS-48
CTR/UTC
8520
8510
2910
Fractional Lambda Pipe 1
Fractional Lambda Pipe 2
Fractional Lambda Pipe 3
8565
Ch 1
Receive Delineation and De-framing Controller
8550
8535
8530
SONET MUX
Ch 2
2910
52
8445
52
A
B
8565
8515
8550
8535
8530
Per SONET channel queuing
FLP to SONET Channel Table
8540
8445
From source S
STS-1
STS-1
STS-1
8560
8500
FLP = Fractional Lambda Pipe

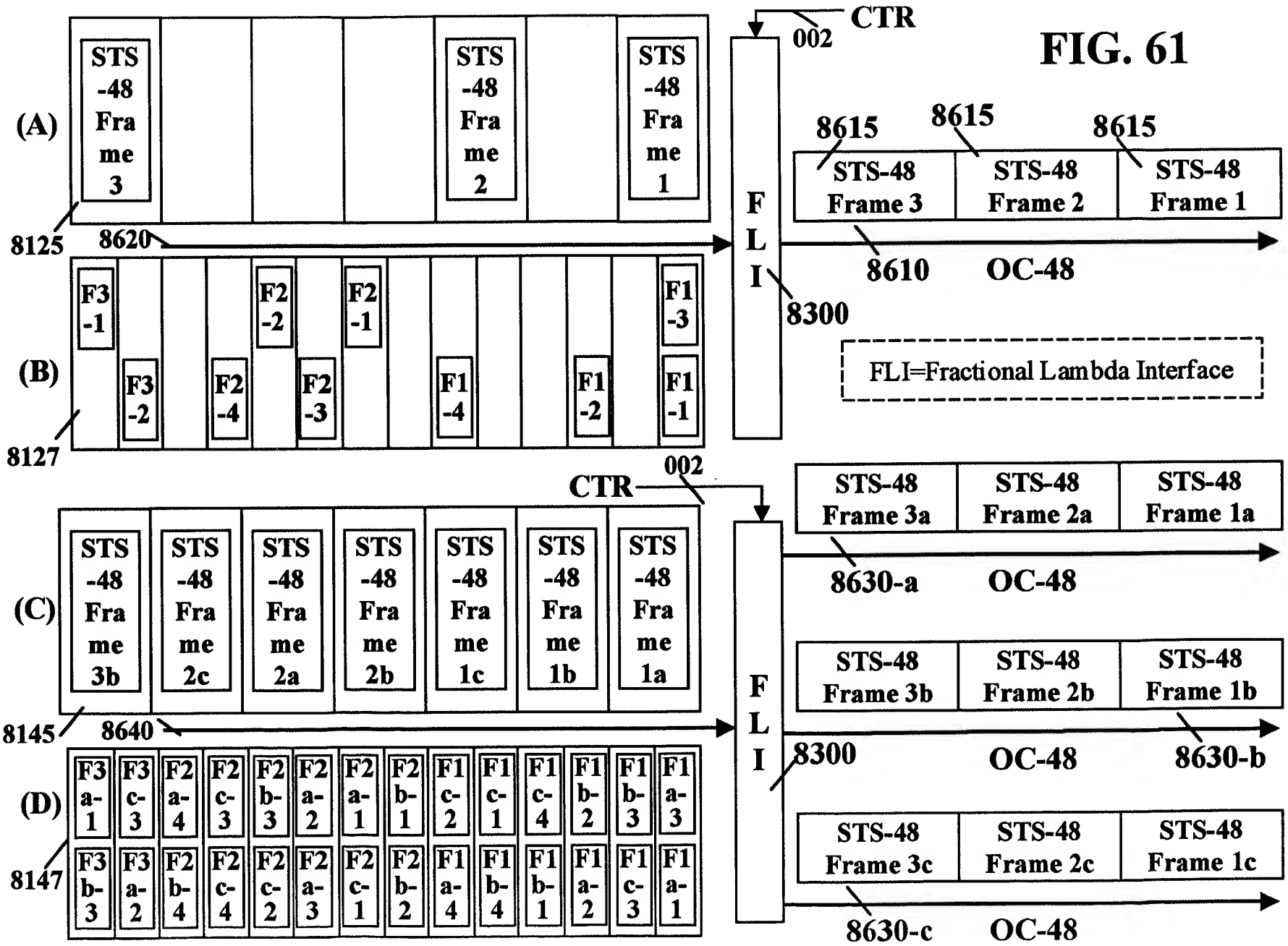

(A)
STS -48 Fra me 3
STS -48 Fra me 2
STS -48 Fra me 1
8125
8620
(B)
F3 -1
F3 -2
F2 -4
F2 -2
F2 -3
F2 -1
F1 -4
F1 -2
F1 -3
F1 -1
8127
CTR
002
F L I
8300
8615
8615
8615
STS-48 Frame 3
STS-48 Frame 2
STS-48 Frame 1
8610
OC-48
FLI=Fractional Lambda Interface
(C)
STS -48 Fra me 3b
STS -48 Fra me 2c
STS -48 Fra me 2a
STS -48 Fra me 2b
STS -48 Fra me 1c
STS -48 Fra me 1b
STS -48 Fra me 1a
8145
8640
(D)
F3 a-1
F3 c-3
F2 a-4
F2 c-3
F2 b-3
F2 a-2
F2 a-1
F2 b-1
F1 c-2
F1 c-1
F1 c-4
F1 b-2
F1 b-3
F1 a-3
F3 b-3
F3 a-2
F2 b-4
F2 c-4
F2 c-2
F2 a-3
F2 c-1
F2 b-2
F1 a-4
F1 b-4
F1 b-1
F1 a-2
F1 c-3
F1 a-1
8147
STS-48 Frame 3a
STS-48 Frame 2a
STS-48 Frame 1a
8630-a
OC-48
STS-48 Frame 3b
STS-48 Frame 2b
STS-48 Frame 1b
8630-b
STS-48 Frame 3c
STS-48 Frame 2c
STS-48 Frame 1c
8630-c

FIG. 61

FIG. 62

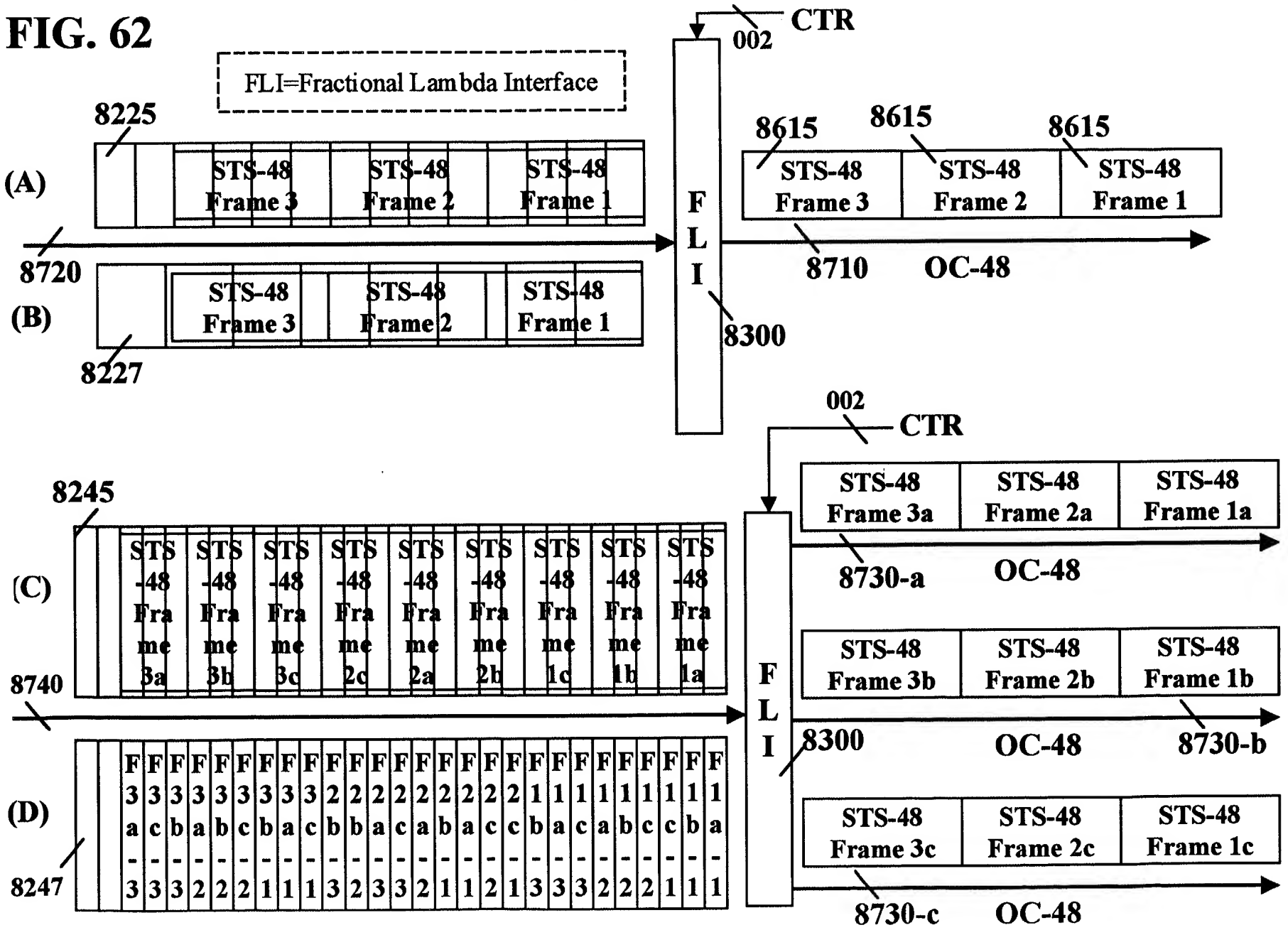

FLI=Fractional Lambda Interface
CTR
002
8225
(A)
STS-48 Frame 3
STS-48 Frame 2
STS-48 Frame 1
8720
(B)
8227
F L I
8300
8615
8615
8615
8710
OC-48
8245
(C)
STS -48 Fra me 3a
STS -48 Fra me 3b
STS -48 Fra me 3c
STS -48 Fra me 2c
STS -48 Fra me 2a
STS -48 Fra me 2b
STS -48 Fra me 1c
STS -48 Fra me 1b
STS -48 Fra me 1a
8740
(D)
8247
STS-48 Frame 3a
STS-48 Frame 2a
STS-48 Frame 1a
8730-a
OC-48
STS-48 Frame 3b
STS-48 Frame 2b
STS-48 Frame 1b
8730-b
STS-48 Frame 3c
STS-48 Frame 2c
STS-48 Frame 1c
8730-c

FIG. 63

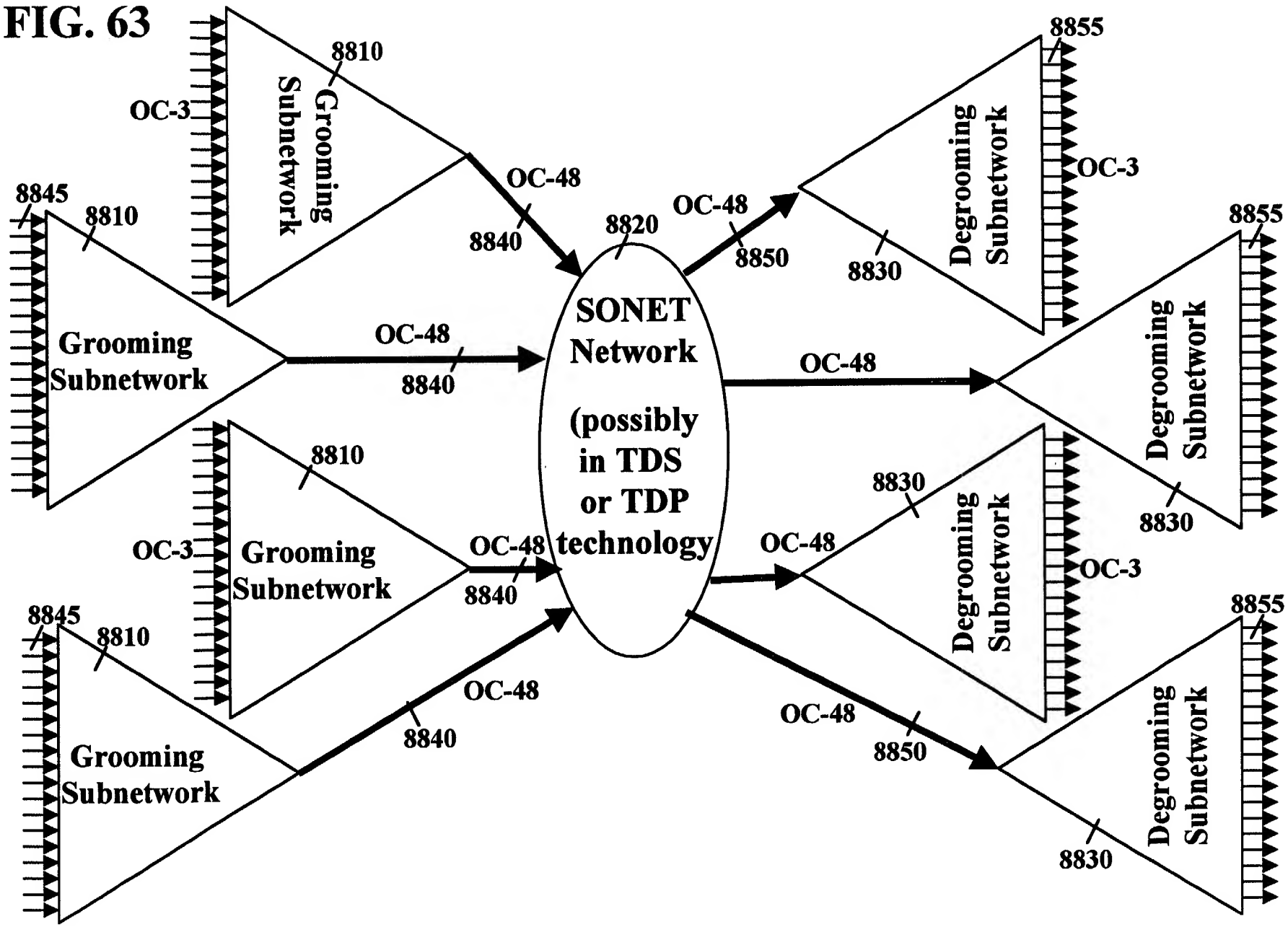

8810
OC-3
Grooming Subnetwork
OC-48
8840
8845
8810
Grooming Subnetwork
OC-48
8840
8820
SONET Network
(possibly in TDS or TDP technology
OC-48
8850
8830
Degrooming Subnetwork
8855
OC-3
8855
Degrooming Subnetwork
8830
OC-48
8810
OC-3
Grooming Subnetwork
OC-48
8840
8830
Degrooming Subnetwork
OC-3
OC-48
8845
8810
Grooming Subnetwork
OC-48
8840
OC-48
8850
8855
Degrooming Subnetwork
8830

FIG. 64

- SONET - synchronous optical network
- Multiplexing method: byte interleaving
- Signal hierarchy: OC-N (STS-N)
  - STS-N rate: N*51.84 Mb/s
  - Frame format: 9 rows by 90*N columns
    - capacity: N*810 bytes in 125 microsecond.
    - overhead: N*27 bytes
    - payload: N*783 bytes

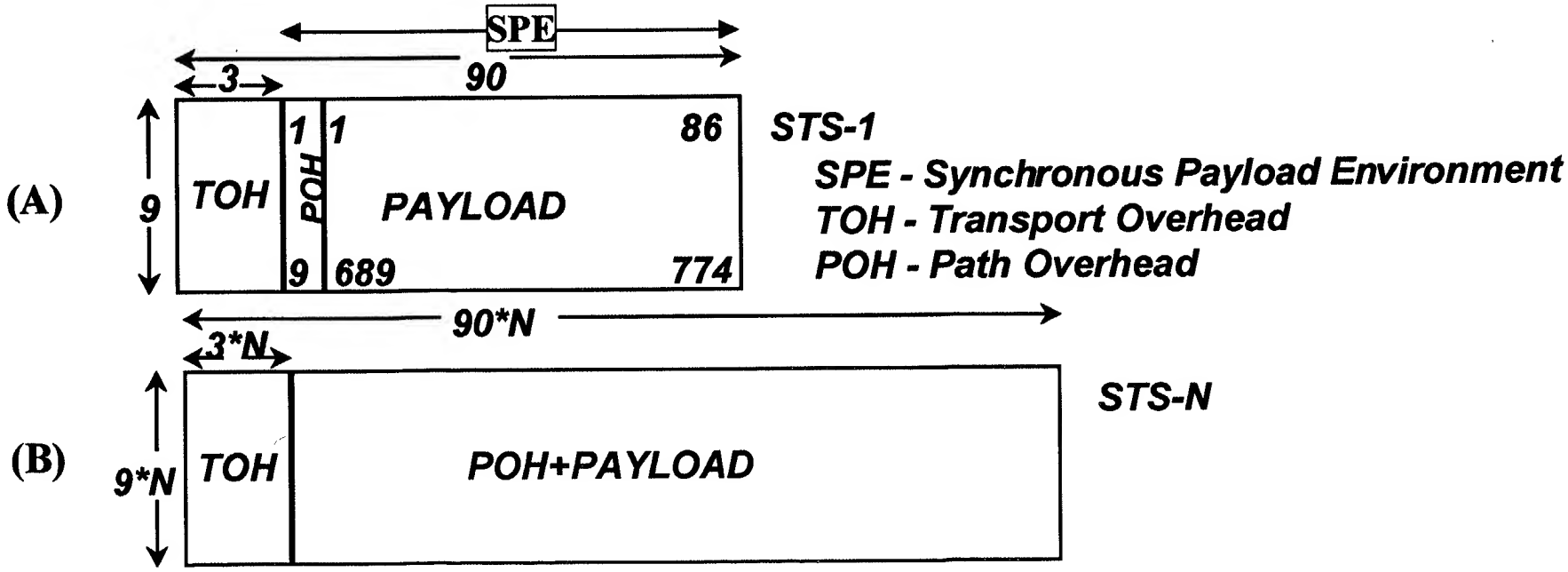
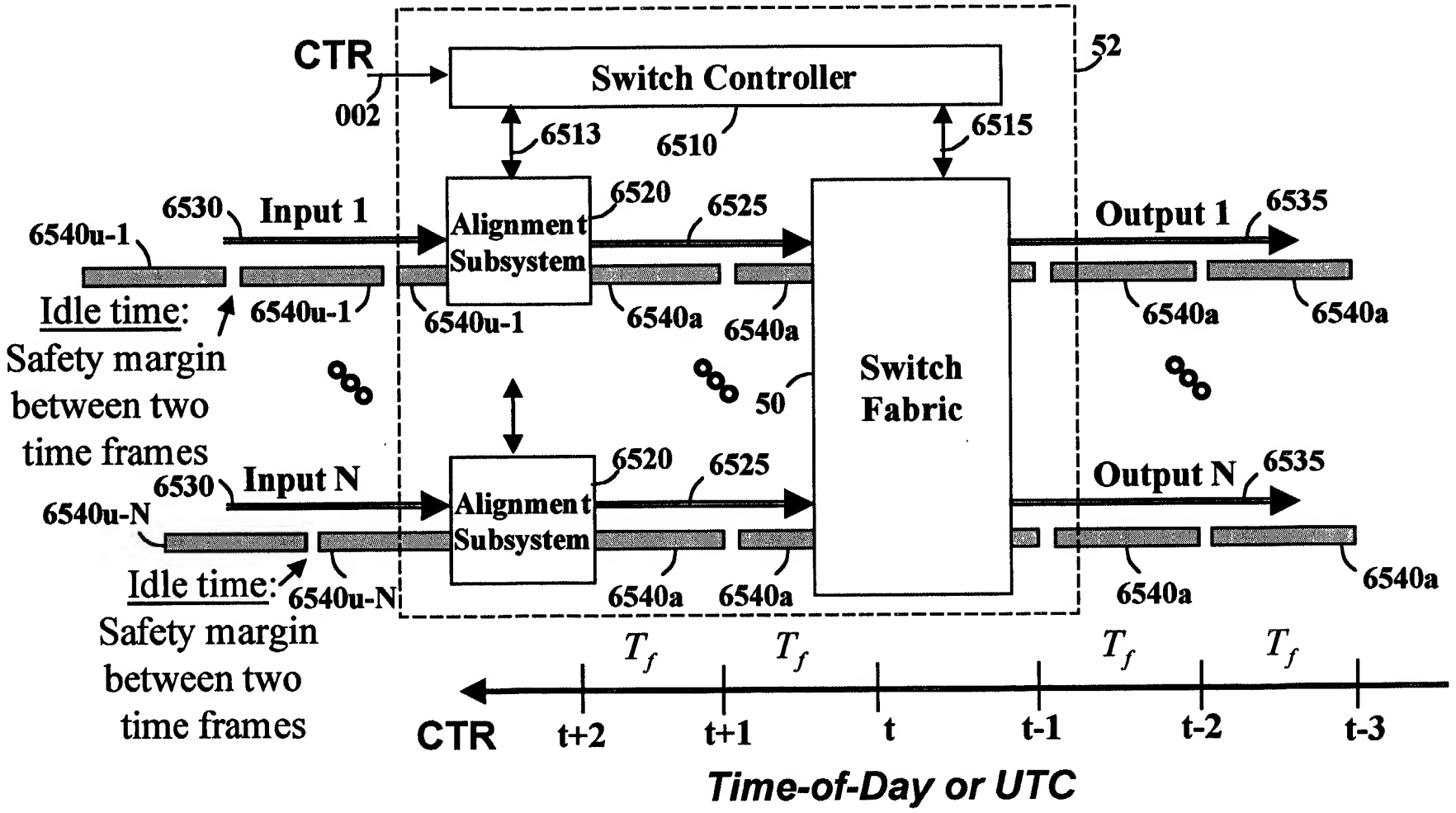


FIG. 65


CTR
002
Switch Controller
52
6513
6510
6515
6530
Input 1
6520
6525
Alignment Subsystem
Output 1
6535
6540u-1
Idle time:
Safety margin between two time frames
6540a
Switch Fabric
50
Input N
6540u-N
Output N
T_f
CTR
t+2
t+1
t
t-1
t-2
t-3
Time-of-Day or UTC
6540
: Time frame
: Time frame payload – with a predefined number of data units